Verbal Chess using Computer Vision with the Baxter Research Robot

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Verbal Chess using Computer Vision with the Baxter Research Robot

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Supervisor: Victor Bershinsky
Date: May 2, 2018

EE4830-Senior Design II Final Report
Department of Electrical and Computer Engineering
College of Engineering and Applied Science
University of Wyoming
Abstract
The Baxter robotic system is an extremely sophisticated piece of machinery, equipped with a myriad of sensors and features. As of yet, very little research has been accomplished utilizing Baxter by students or faculty in the Department of Electrical and Computer Engineering at the University of Wyoming. This project is a base that will enable future employment of Baxter for more intricate and advanced research topics. This project was derived to showcase a large portion of Baxter’s functionality in an easily digestible and potentially expandable format. It will display a convenient form of user interaction (voice commands), utilization of computer vision (detecting chess board and pieces), and safe and precise physical interactions with or near humans (moving chess pieces).

The goal of this project is to enable the Baxter robotic system to move chess pieces on a chess board based on user input in the form of voice commands. This can be broken up into four main parts: physical movement of Baxter’s appendages, computer vision to locate the board and chess pieces, voice recognition and speech output for the necessary set of commands, and internal chess board state information and chess logic.

Background Information
Baxter has two arms with seven degrees of freedom; each of which is equipped with a pair of grippers and a high definition camera on the end. The Baxter Research Robot SDK interfaces with Baxter via the Robot Operating System (ROS) and its various ROS APIs. This project utilizes the camera on the end of the left arm to capture the chess board and pieces. Prewritten Python and ROS libraries, including pocketsphinx, Baxter’s Inverse Kinematics Service, pyttsx, and OpenCV are employed to enable computer vision, speech recognition, speech output, and arm movements. This project is intended to be a stepping stone for future applications and a proof of concept of the Baxter Research Robot’s capabilities and use as many Baxters abilities to play a game of chess, through our learning of ROS. The only things that changed from the original design goals were a team member change and a slight change in how the computer vision worked, in that baxter did not find unique pieces just the closest piece to the proper location of the piece.

Functional and Technical Specifications
Baxter Research Robot
Baxter has two seven degree-of-freedom (DOF) arms that utilize Series Elastic Actuators. It has an arm span of 261 cm and a height of 185 cm. On the end of each arm is a pair of replaceable grippers. The only actions the grippers are capable of are opening and closing (as the grippers are only composed of two digits). Baxter is equipped with a camera on the end of both arms. The Baxter Research Robot SDK provides a software interface for developing custom applications to run on the Baxter platform. The SDK interfaces with Baxter via the Robot Operating System (ROS) and its various ROS APIs.

Operation
The ‘README.md’ file on this team’s GitHub describes the necessary operations to initialize and operate this project. The following will describe the details of the operations that were created in order to make Baxter play chess.

Computer Vision and Movement: Initialization
The initialization of Baxter was done through the running of a camera control tool that would open and close the left hand camera in a specific order that way the camera was set up to a resolution of 960x600. This was done so the computer vision algorithms knew the proper pixel count for further usage. The next step was to then have Baxter hover above the chess board at a height of 62 cm then view the space and find the largest enclosed shape, which happened to be the chess board. Baxter would then approach the middle of the board and locate the corners. This process was all defined under a method called CannyIt. Lastly a formula was derived to align the picture coordinates with Baxters coordinates so the middle of each square on the chess board could be turned into a pose that Baxter would eventually move to.

Speech Recognition
Speech recognition was accomplished utilizing a package developed by the Carnegie Mellon University Sphinx team called ‘pocketsphinx.’ A text file, ‘speech_commands.txt’ included in appendices, was created with a list of all commands that needed to be recognized for operation of the chess game. A handful of other files were generated from this file using an online tool, which were utilized by the main script for speech recognition, ‘recognizer.py.’ This script does the heavy lifting for integration with the default microphone input of the connected computer and determines whether any of that input matches a word or phrase from the dictionary text file. If there is a match, the script publishes that information to the ROS Topic ‘/recognizer/output/’. ROS Topics are essentially streams of
information maintained by the master node (the Baxter robot, itself) to and from which other nodes (scripts that are run connected to the master node) can post and access information through the standard form of ROS message data types.

**Speech Output**

Speech output works in a similar way to speech recognition. A server code is run, which connects to the default audio output device of the computer linked to the Baxter Research Robot. A client script then connects to the server through a three-way TCP handshake, and indicates the desired voice output with a function whose input is the desired voice output as a python string. That string is then converted by the server to an audio, speech file utilizing the pyttsx, python text to speech, library and played by the connected speaker. Speech output is utilized to indicate to the user the state of the chess game and the next expected voice input. All of the outputs utilized can be found in the ‘voicecommands.py’ script included in the appendices as all the definitions of the variable ‘what_to_say.’

**Computer Vision and Movement: Pieces**

The next step as far as computer vision was concerned was how to properly pick up a piece to move from one square to the next. This was done through approaching the pose that was determined in initialization and hovering over that area, this in effect would be close to being directly over the desired piece. Then Baxter would take another picture and using a method called findContours, the piece would be found by identifying the color difference between the piece and its background. After the piece is found a moment calculation was performed to find the center of the piece and converted from pixel coordinates to Baxter’s coordinates. Once Baxter has the new coordinates of the exact location of the piece the pose is updated and the move is performed. The move is performed by calling Baxter’s IK servers that link two poses, this service figures out the best way to get from one position to the next so the exact movement between poses could vary. For this reason a middle ground coordinate was programmed in that would make sure Baxter was always moving away from the board in order to preserve its correct state. The last step to perfecting this method was determining the offsets and the meters per pixel of each picture to try and fine tune piece location as much as possible.

**Virtual Chess Board and Logic**

The goal of the chess logic was to maintain a virtual representation of the physical chess board. This was needed so that two main functionalities could be achieved. Primarily, there needed to be a check on whether or not a proposed move was valid. This included checking on whose turn it was, what kind of piece was being moved, and where it was being moved to. The generic algorithm used to perform this verification is shown in the figure below. Once a move was determined to be valid Baxter would perform the physical movement. Afterwards, the user would verify that the move has successfully been completed. Secondly, to ensure the parallelism of the virtual board and physical board the state of the virtual board needed to be updated after the physical piece was moved. This involved swapping important object data members from one location to another. For example, Piece A at Location 1 is moved to Location 2. The information that was originally at location 2 is overwritten by the information that was at Location 1. Then the information at Location 1 is overwritten with the information of the “Null” piece. The “Null” piece is a virtual construct which is used to represent an empty square on the board. Refer to the code appendix for the actual Python implementation of the chess logic.
Component Integration
All the various components of this project were developed independently of each other and combined later to make a cohesive whole. The original design was to integrate everything utilizing the ROS Topic utility; however, each separate portion of code was constructed largely using classes that could be easily imported and utilized in other scripts. This enabled the use of one main, driver code with imports of the various developed classes, providing all the necessary functionality to integrate and execute the entire project as desired. As such, because the direction of execution is determined by voice commands, that became the base code in which to import all the other classes. The ‘voicecommands.py’ script immediately executes the board location initialization, then executes all other operations (piece movement, functional operations, move validation, and updating virtual board state) as determined by receipt of valid voice commands from the user.

Software Flow Chart and Schematics
This diagram includes the main sections of code (as the rectangles), inputs into the system (as the Circles), and decisions in the code logic (as the hexagons). The utilized libraries are also included is the rounded rectangles inside the blocks of code in which they will be utilized.
Object Oriented Design of Chess Logic:
Results

Computer Vision and Movement: Initialization
The board is found and the corners are properly found and placed as coordinates at an error range of .007m, which gives each center of the square an error of about 1.2cm in any direction. Below shows the output to the user on how the computer vision should look for a successful finding of the board and marking of coordinates for each square on the chess board.

Speech Recognition
Speech recognition can become inconsistent under the following conditions: there is background noise interfering with the quality of voice input, words included in the recognition library are overly simple or similar, or the enunciation of the user is poor due to light consonant sounds, uneven volume, and very low or high pitched voices. Our command library was changed to use the NATO phonetic alphabet (alpha, bravo, charlie, delta, echo, foxtrot, golf, and hotel) rather than the letters a-h, as well as the response of ‘success’ or ‘failure’ rather than ‘yes’ or ‘no’ to
minimize the occurrence of incorrect interpretations and false positives of commands. Outside of the aforementioned conditions, speech recognition accuracy is upwards of 95%.

**Speech Output**

As the speech output technique was relatively simple, it consistently worked properly. The only issue is that if the output volume is increased too much, it can affect the input of voice commands.

**Computer Vision and Movement: Pieces**

Piece movement took a lot of trial and error to properly pick up a piece. Through experimentation it was found that Baxter was on average about 8cm off in the Y direction and 4cm off in the X direction from where he thought he was at a height of 32cm from the board. These offsets were then sent into the conversion function that changed picture pixel coordinates to Baxter coordinates. at a height of 16cm the Y offset was 3.3cm and the x was still 4cm. The pieces were found using a findContours function that would just look for the color difference of each pixel and note the change as a coordinate that was used for a moment calculation and a canter value of the piece. Below shows how the findContours function should look when finding a piece.

Notice that multiple shapes are found, the piece that is picked should have a center closest to the center of the picture keeping in mind of the current offsets from the grippers to the center of the picture. The movement worked as it should once Baxter had the correct coordinates and pose to move to.

**Virtual Chess Board and Logic**

The goal of the virtual chess board and logic component of this project was to accurately represent the physical layout of the chess board virtually using the Python programming language. Using this created framework the important tasks such as move validation, killing a piece, when the game is over, and updating the state of the virtual board could be answered. The result to this work was a complete success. Every task that was implemented in the using the chess logic code worked without bugs or errors. Below is an example of output that my code can produce in the terminal which was used multiple times for debugging purposes.
Component Integration
The entire projects works together properly as desired. All goals, after slight modification as a result of losing a team member, were successfully accomplished. User interaction through voice commands and responses was successfully implemented, computer vision paired with physical movements work properly, and the chess logic is accurate and successfully integrated into operation.

Future Considerations
Due to time constraints there were some areas of this project where similar projects could improve on our progress. This includes using a more robust computer vision algorithm which would be more resistant to variations in ambient light as well as being able to detect more general shapes of objects in order to differentiate between chess pieces and enable the ability to initialize the project with a chess game that is already in progress. One other improvement that could be made is to utilize the MoveIt movement library, rather than Inverse Kinematics; MoveIt can include and avoid physical obstacles when deciding how to move from one location to another.

Acknowledgements
A special thanks to the following people who contributed heavily to making this project possible: Deborah Kretzschmar, Dr. Suresh Muknahallipatna, and Victor Bershinky.

Appendices
Unused code, reference files, and old versions of files can be found in the Github repository located at the following address: https://github.com/zephconnell/Baxter_Chess
This repository can also be utilized as a reference for the directory structure of the project as implemented. The ‘Baby Steps’ folder in the repository (implemented as ‘baby_steps’ on the linux computer connected to the Baxter Research Robot) specifically is the final version of the ROS workspace package that was utilized for this project. All code and files utilized for final operation of this project are included in the appendices below.
References and General Functionality Code

README.md

- How to run Open terminal
  cd ros_ws ./baxter.sh roslaunch baby_steps speech_commands.launch
  new terminal
  cd ros_ws ./baxter.sh rosrun baby_steps pyttsx_server.py
  new terminal
  cd ros_ws ./baxter.sh rosrun baby_steps camera.py rosrun baby_steps voicecommands.py

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This package contains a "mish-mosh" of ideas and code snippets from several sources. This includes Rethink Robotics, "ROS by Example" by Patrick Goebel, "Programming Robots with ROS" by Morgan Quigley, Brian Gerkey and William Smart, ROS Tutorials about the turtlesim and transformation, Turtlesim tutorials by Professor Anis Koubaa, and the Robotics Laboratory at Sun Yat-sen University called the Biomimetics and Intelligent Robotics Lab (BIRL) run by Dr. Rojas. The BIRL robotics lab has a very helpful wiki which contains tutorials and shows their work.

In addition, the Neuroscience and Robotics lab at Northwestern University had a demo using Baxter. Their idea to use an adaptive double exponential smoothing filter and some vector operations were used in this package.

Although the information used is open source, some had different types of open source licenses, so several are listed in this text.

They licenses listed below in order:

(1) Rethink Robotics
(2) "Programming Robots with ROS" by Morgan Quigley et al.
(3) "ROS by Example" by Patrick Goebel
(4) ROS Tutorials
(5) Use of pyttsx a cross-platform Python wrapper for text-to-speech synthesis
   It was written by Peter Parente
(6) CMU Sphinx (Carnegie University Sphinx) at http://cmusphinx.sourceforge.net/
(7) Micheal Ferguson wrote the ROS pocketsphinx package for speech recognition.

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Michael Ferguson's package for pocketsphinx

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package.xml

<?xml version="1.0"?>
<package>
  <name>baby_steps</name>
  <version>0.0.0</version>
  <description>The baby_steps package</description>

  <!-- One maintainer tag required, multiple allowed, one person per tag -->
  <!-- Example: -->
  <!-- <maintainer email="jane.doe@example.com">Jane Doe</maintainer> -->
  <maintainer email="baxter@todo.todo">baxter</maintainer>
<!-- One license tag required, multiple allowed, one license per tag -->
<!-- Commonly used license strings: -->
<!-- BSD, MIT, Boost Software License, GPLv2, GPLv3, LGPLv2.1, LGPLv3 -->
<license>TODO</license>

<!-- Url tags are optional, but multiple are allowed, one per tag -->
<!-- Optional attribute type can be: website, bugtracker, or repository -->
<!-- Example: -->
<!-- <url type="website">http://wiki.ros.org/baby_st</url> -->

<!-- Author tags are optional, multiple are allowed, one per tag -->
<!-- Authors do not have to be maintainers, but could be -->
<!-- Example: -->
<!-- <author email="jane.doe@example.com">Jane Doe</author> -->

<!-- The *_depend tags are used to specify dependencies -->
<!-- Dependencies can be catkin packages or system dependencies -->
<!-- Examples: -->
<!-- Use build_depend for packages you need at compile time: -->
<!-- <build_depend>message_generation</build_depend> -->
<!-- Use buildtool_depend for build tool packages: -->
<!-- <buildtool_depend>baxter_core_msgs</buildtool_depend> -->
<!-- Use run_depend for packages you need at runtime: -->
<!-- <run_depend>message_runtime</run_depend> -->
<!-- Use test_depend for packages you need only for testing: -->
<!-- <test_depend>gtest</test_depend> -->
<!-- <buildtool_depend>catkin</buildtool_depend> -->
<!-- <build_depend>actionlib</build_depend> -->
<!-- <build_depend>baxter_core_msgs</build_depend> -->
<!-- <build_depend>baxter_interface</build_depend> -->
<!-- <build_depend>control_msgs</build_depend> -->
<!-- <build_depend>cv_bridge</build_depend> -->
<!-- <build_depend>dynamic_reconfigure</build_depend> -->
<!-- <build_depend>rospy</build_depend> -->
<!-- <build_depend>sensor_msgs</build_depend> -->
<!-- <build_depend>trajectory_msgs</build_depend> -->
<!-- <build_depend>xacro</build_depend> -->
<!-- <build_depend>message_generation</build_depend> -->
<!-- <run_depend>actionlib</run_depend> -->
<!-- <run_depend>baxter_core_msgs</run_depend> -->
<!-- <run_depend>baxter_interface</run_depend> -->
<!-- <run_depend>control_msgs</run_depend> -->
<!-- <run_depend>cv_bridge</run_depend> -->
<!-- <run_depend>dynamic_reconfigure</run_depend> -->
<!-- <run_depend>rospy</run_depend> -->
<!-- <run_depend>sensor_msgs</run_depend> -->
<!-- <run_depend>trajectory_msgs</run_depend> -->
<!-- <run_depend>xacro</run_depend> -->
<!-- <run_depend>message_generation</run_depend> -->

<!-- The export tag contains other, unspecified, tags -->
<export>
<!-- Other tools can request additional information be placed here -->

</export>
</package>

CMakeLists.txt

```
cmake_minimum_required(VERSION 2.8.3)
project(baby_steps)

## Compile as C++11, supported in ROS Kinetic and newer
# add_compile_options(-std=c++11)

## Find catkin macros and libraries
```
## if COMPONENTS list like find_package(catkin REQUIRED COMPONENTS xyz)
## is used, also find other catkin packages
find_package(catkin REQUIRED COMPONENTS
  actionlib
  baxter_core_msgs
  baxter_interface
  control_msgs
  cv_bridge
  dynamic_reconfigure
  rospy
  sensor_msgs
  trajectory_msgs
  xacro
)

## System dependencies are found with CMake's conventions
# find_package(Boost REQUIRED COMPONENTS system)

## Uncomment this if the package has a setup.py. This macro ensures
## modules and global scripts declared therein get installed
# catkin_python_setup()

############################################
## Declare ROS messages, services and actions ##
################################################
## To declare and build messages, services or actions from within this
## package, follow these steps:
## * Let MSG_DEP_SET be the set of packages whose message types you use in
##   your messages/services/actions (e.g. std_msgs, actionlib_msgs, ...).
## * In the file package.xml:
##   * add a build_depend tag for "message_generation"
##   * add a build_depend and a run_depend tag for each package in MSG_DEP_SET
##   * If MSG_DEP_SET isn't empty the following dependency has been pulled in
##     but can be declared for certainty nonetheless:
##       * add a run_depend tag for "message_runtime"
## * In this file (CMakeLists.txt):
##   * add "message_generation" and every package in MSG_DEP_SET to
##     find_package(catkin REQUIRED COMPONENTS ...)
##   * add "message_runtime" and every package in MSG_DEP_SET to
##     catkin_package(CATKIN_DEPENDS ...)
## * uncomment the add_*_files sections below as needed
##   * list every .msg/.srv/.action file to be processed
## * uncomment the generate_messages entry below
##   * uncomment the generate_messages entry below
## Generate messages in
## the 'msg' folder
# add_message_files(
#   FILES
#   Message1.msg
#   Message2.msg
# )

## Generate services in the 'srv' folder
# add_service_files(
#   FILES
#   Service1.srv
#   Service2.srv
# )

## Generate actions in the 'action' folder
add_action_files(
  FILES
  #Action1.action
  Talk.action
)

## Generate added messages and services with any dependencies listed here
generate_messages(
    DEPENDENCIES
    actionlib_msgs baxter_core_msgs# control_msgs# sensor_msgs# trajectory_msgs
)
#
# To declare and build dynamic reconfigure parameters within this
# package, follow these steps:
# * In the file package.xml:
#   * add a build_depend and a run_depend tag for "dynamic_reconfigure"
# * In this file (CMakeLists.txt):
#   * add "dynamic_reconfigure" to
#     find_package(catkin REQUIRED COMPONENTS ...)
# * uncomment the "generate_dynamic_reconfigure_options" section below
#   and list every .cfg file to be processed
#
# Generate dynamic reconfigure parameters in the 'cfg' folder
# generate_dynamic_reconfigure_options(
#   cfg/DynReconf1.cfg
#   cfg/DynReconf2.cfg
# )
#
# catkin specific configuration
#
# The catkin_package macro generates cmake config files for your package
# Declare things to be passed to dependent projects
# LIBRARIES: uncomment this if you package contains header files
# CATKIN_DEPENDS: catkin_packages dependent projects also need
# DEPENDS: system dependencies of this project that dependent projects also need

catkin_package(
    INCLUDE_DIRS include
    LIBRARIES baby_steps
    CATKIN_DEPENDS actionlib baxter_core_msgs baxter_interface control_msgs cv_bridge dynamic_reconfigure rosy sensor_msgs trajectory_msgs xacro
    DEPENDS system_lib
)
#
# Build
#
# Your package locations should be listed before other locations
# include_directories(
#   # include
#   ${catkin_INCLUDE_DIRS}
# )
#
# Declare a C++ library
# add_library(${PROJECT_NAME}
#   src/${PROJECT_NAME}/baby_steps.cpp
# )
#
# Add cmake target dependencies of the library
# as an example, code may need to be generated before libraries
# either from message generation or dynamic reconfigure
# add_dependencies(${PROJECT_NAME} ${${PROJECT_NAME}_EXPORTED_TARGETS} ${catkin_EXPORTED_TARGETS})
#
# Declare a C++ executable
# With catkin_make all packages are built within a single CMake context
# The recommended prefix ensures that target names across packages don't collide
# add_executable(${PROJECT_NAME}_node src/baby_steps_node.cpp)
#
# Rename C++ executable without prefix
# The above recommended prefix causes long target names, the following renames the
## Install

all install targets should use catkin DESTINATION variables

## Testing

Add gtest based cpp test target and link libraries

Add folders to be run by python nosetests

### camera.py

```python
#!/usr/bin/env python

import rospy
import std_srvs.srv
from baxter_core_msgs.srv import (ListCameras,
```
import sys
import baxter_interface

from baxter_interface.camera import CameraController

import subprocess

rospy.init_node("camera", anonymous = True)

""
It is very important to have the rospy.sleep
in between each call to the camera service.
You must allow a minimum of 10 seconds which
is why the sleep was set to 11 seconds.
If not, then a subsequent call to the camera
service is coming from the same node and
you will get an error.
""

listCameras = 'rosrun baxter_tools camera_control.py -l'
closeLeft = 'rosrun baxter_tools camera_control.py -c left_hand_camera'
closeHead = 'rosrun baxter_tools camera_control.py -c head_camera'
openLeft = 'rosrun baxter_tools camera_control.py -o left_hand_camera -r 960x600'

subprocess.Popen(listCameras, shell=True)
rospy.sleep(11)
subprocess.Popen(closeLeft, shell = True)
rospy.sleep(11)
print("The left hand camera was closed")
subprocess.Popen(closeHead, shell = True)
rospy.sleep(11)
print("The head camera was closed")
subprocess.Popen(openLeft, shell = True)
print("The left hand camera was opened at resolution 960 by 600")
# needed to find the path to where the images are stored
import rospkg
import cv;
import cv2;
# cv_bridge is the interface between ROS and openCV.
# you will find tutorials on how to convert OpenCV images to ROS sensor_msgs/Image messages
import cv_bridge

from sensor_msgs.msg import Image

RETHINK IMPORTS

import baxter_interface

from baxter_interface import CHECK_VERSION
# open cv and cv2 are used to create the images published to Baxter's topic /robot/xdisplay
import cv;
import cv2;
# cv_bridge is the interface between ROS and openCV.
# you will find tutorials on how to convert OpenCV images to ROS sensor_msgs/Image messages
import cv_bridge

# we have to import the message type used to publish to the topic /robot/xdisplay
from sensor_msgs.msg import Image

# this class resets Baxter arms to neutral, resets the facescreen, makes sure the grippers are
# open and then disables the motors. Code snippets borrowed from rethink examples
class Reset(object):
    def __init__(self):
        self._left_arm = baxter_interface.limb.Limb("left")
        self._right_arm = baxter_interface.limb.Limb("right")
        self._rp = rospkg.RosPack()
        self._images = (self._rp.get_path('baby_steps') + '/Share/images')
        self.pub = rospy.Publisher('/robot/xdisplay', Image, latch=True, queue_size=10)
        print("Getting robot state... ")
        self._rs = baxter_interface.RobotEnable(CHECK_VERSION)
        self._init_state = self._rs.state().enabled
        print("Enabling robot... ")
        self._rs.enable()
        self.right_gripper = baxter_interface.Gripper("right")
        self.left_gripper = baxter_interface.Gripper("left")

    def set_neutral(self):
        print("Moving to neutral pose...")
        self._left_arm.move_to_neutral()
        self._right_arm.move_to_neutral()

    def reset_facescreen(self):
        print('Resetting facescreen')
        img = cv2.imread(self._images + '/default.png')
        msg = cv_bridge.CvBridge().cv2_to_imgmsg(img, encoding= "bgr8")
        self.pub.publish(msg)

    def grippers_reset(self):
        if self.right_gripper.error():
            print("right gripper error, will reset")
            self.right_gripper.reset()

        if self.left_gripper.error():
            print("left gripper error, will reset")
            self.left_gripper.reset()}
if not self.left_gripper.calibrated():
    print("ncalibrating left gripper")
    self.left_gripper.calibrate()

if not self.right_gripper.calibrated():
    print("ncalibrating right gripper")
    self.right_gripper.calibrate()
    print("Make sure grippers are open")
    self.right_gripper.open()
# this just puts ros to sleep for 1 sec
rospy.sleep(1)
self.left_gripper.open()

def disable_motors(self):
    if not self._init_state:
        print("Disabling robot...")
        self._rs.disable()
    else:
        print("Disabling the robot...")
        self._rs.disable()
    return True

def main():
    print("Initializing node...")
    rospy.init_node("reset", anonymous = True)
    reset = Reset()
    reset.set_neutral()
    reset.reset_facescreen()
    reset.grippers_reset()
    reset.disable_motors()

    print("Baxter's arms now in neutral position, led display back to rethink log and motors have been disabled.")

if __name__ == '__main__':
    main()

---

Files Utilized, Modified, and Developed by Connor Desmond

---

Files Utilized, Modified, and Developed by Ryan Cook

chess_real2.py

#!/usr/bin/env python

"""
ROS IMPORTS
"""
#this is a pure Python client library for ROS. It allows programmers using python
# to interface with ROS
import rospy
#cv_bridge is the interface between ROS and openCV,
#here is the web address for the tutorial:
# http://wiki.ros.org/cv_bridge/Tutorials/ConvertingBetweenROSImagesAndOpenCVImagesPython
# you will find tutorials on how to convert OpenCV images to ROS sensor_msgs/Image messages
import cv_bridge
from cv_bridge import CvBridge, CvBridgeError
# read about tf (transform) here: http://wiki.ros.org/tf/Tutorials
# there is a tf2 now...program works fine with tf
# here is the info for tf2 should you decide you want to use it: http://wiki.ros.org/tf2
# The web page also contains links to tutorials.
#if I put some formulas to convert back and forth between Euler and Quaternions at the bottom of the page
import if
# remember that ROS uses topics and streams the data in messages (msgs).
# this program subscribes to the topic /cameras/left_hand_camera/image (assuming you are using the left hand camera)
# If you type in cd ros_ws, then get into Baxter's shell by typing ./baxter.sh and then finally type
# rostopic info /cameras/left_hand_camera/image .....it will display that the message type for
# the topic /cameras/left_hand_camera/image is sensor_msgs/Image.
# this is the reason you need to import the sensor_msgs/Image
from sensor_msgs.msg import Image
# this program uses other ROS message types, particulary, when
# the ik service is used.
# Here is a link to the geometry_msgs so that you can see all
# the message types. These message types are used particularly
# when doing transformations.
# http://wiki.ros.org/geometry_msgs
# if you click on any of the message types at the website, the
# message definition will be displayed.
from geometry_msgs.msg import (PoseStamped,
Pose,
Point,
Quaternion,
)
# information on standard message types are found here:
#http://wiki.ros.org/std_msgs
# the header will be used to build pose_stamped msg sent to
# Baxter's ik service which is called
# /ExternalTools/left/PositionKinematicsNode/IKService
# if you were to type in rosservice info /ExternalTools/left/PositionKinematicsNode/IKService
# it would show you that the msg type is baxter_core_msgs/SolvePositionIK
# and that one of the arguments is a pose_stamped msg. (which needs a header)
# The Empty message is used to ensure that the simulator is ready to go.
# It is from the line of code: rospy.wait_for_message("/robot/sim/started", Empty)
# The simulator has a topic called "/robot/sim/started" which puts out an empty message
# once it is ready to go. You would not need this for the real robot.
from std_msgs.msg import (Header,
Empty,
)

# common ros msgs including service (srv) http://wiki.ros.org/common_msgs
import std_srvs.srv

#this allows one to query about ros packages
# in this program it is used to find the path to image files which
# are used to reset Baxter's LCD "face" during the shut down process
import rospkg

#These are the gazebo_msgs needed to spawn and delete models
from gazebo_msgs.srv import (SpawnModel,
DeleteModel,
)

import imutils

****
PYTHON IMPORTS
****
#the next two imports are for the OpenCV libraries.
****
This example code uses legacy python code for open CV found here:
https://docs.opencv.org/2.4/modules/core/doc/old_basic_structures.html?highlight=createimage#cv.CreateImage
As you get more familiar with Open CV, you may wish to transition to updated versions. (opencv 3.0)
Just be aware that there may be package dependency as well as compatibilty issues with cv_bridge and
move cautiously.
****
import cv
import cv2
#opencv images are converted to and from Numpy arrays
import numpy
import math

import os

import sys

import string

import copy

import baxter_interface

from baxter_interface import CHECK_VERSION

import baxter_interface

"RETHINK IMPORTS"

import baxter_interface

from baxter_interface import CHECK_VERSION

#These are baxter's core_msgs that allow use of
# the IK service
from baxter_core_msgs.srv import (SolutionPositionIK,
    SolvePositionIKRequest,
)

image_directory = os.getenv("HOME") + "/Golf/"

#End of header with all the imports

# Locate class

class Locate():
    def __init__(self, arm, distance):
        global image_directory
        self.sd = ShapeDetector()
        # arm ("left" or "right")
        self.limb = arm
        self._rp = rospkg.RosPack()
        self._images = (self._rp.get_path('baby_steps') + '/Share/images')
        self.limb_interface = baxter_interface.Limb(self.limb)
        self._joint_names = self.limb_interface.joint_names()
        print("Getting robot state....")
        self._rs = baxter_interface.RobotEnable(CHECK_VERSION)
        print("Enabling robot....")
self._rs.enable()

if arm == "left":
    self.other_limb = "right"
else:
    self.other_limb = "left"

self.other_limb_interface = baxter_interface.Limb(self.other_limb)

# gripper ("left" or "right")
self.gripper = baxter_interface.Gripper(arm)

# image directory
self.image_dir = image_directory

# flag to control saving of analysis images
# used in canny_it function
self.save_images = True

# this is borrowed from the pick and place demo from rethink for the simulator
self._hover_distance = .07

# required position accuracy in metres
self.cBoard_tolerance = 0.005
self.tray_tolerance = 0.007

# An orientation for gripper fingers to be overhead and parallel to the obj
# this orientation was "borrowed" from the baxter_simulator example pick and place
self.overhead_orientation = Quaternion(
    x=-0.0249590815779,
y=0.999649402929,
z=0.00737916180073,
w=0.00486450832011)

self.starting_right_joint_angles = {'right_w0': 0.38,
                                     'right_w1': 1.18,
                                     'right_w2': 1.97,
                                     'right_e0': 71,
                                     'right_e1': 2.42,
                                     'right_s0': -0.86,
                                     'right_s1': -2.13}

# number of cBoards found
#self.cBoards_found = 0

# start positions
self.cBoard_tray_x = 0.5 # x = front back
self.cBoard_tray_y = 0.3 # y = left right ----positive for y is to your left as you face forward
self.cBoard_tray_z = 0.35 # z = up down
self.piece_x = 0.50 # x = front back ----positive for x is forward--negative x is back behind you 0.50
self.piece_y = 0.00 # y = left right
self.piece_z = 0.15 # z = up down
self.roll = -1.0 * math.pi # roll = horizontal
self.pitch = 0.0 * math.pi # pitch = vertical
self.yaw = 0.0 * math.pi # yaw = rotation

self.pose = [self.piece_x, self.piece_y, self.piece_z, self.overhead_orientation]

# camera parameters (NB. other parameters in open_camera)****the description for how this was calculated is on the website
self.cam_calib = 0.0025 # meters per pixel at 1 meter .0025
self.cam_x_offset = 0.043 # camera gripper offset
self.cam_y_offset = -0.084 #.01 or -.015
self.cam_y_offset_close = -0.030
self.width = 960 #640 # Camera resolution
self.height = 600 #400
# Hough circle accumulator threshold and minimum radius. These were commented out since Hough circle not being used now.
self.hough_accumulator = 35
self.hough_min_radius = 10
self.hough_max_radius = 50

# canny image--------creates an image header
# parameters: size(image width and height). Here we are using Baxter's hand camera resolutions.
# next is the bit depth of image elements. Most OpenCV functions use mono8 or bgr8. Here we use 8.
# Number of channels per pixel. Most OpenCV functions support 1-4 channels. We are using 1 channel.
self.canny = cv.CreateImage((self.width, self.height), 8, 1)

Canny uses two thresholds—an upper and lower. If a pixel gradient is higher than the upper threshold, the pixel is accepted as an edge. If a pixel gradient value is below the lower threshold, then it is rejected. If the pixel gradient is between the two thresholds, then it will be accepted only if it is connected to a pixel that is above the upper threshold.
Recommended upper:lower ration between 2:1 and 3:1

# Canny transform parameters
self.canny_low = 45
self.canny_high = 150

# minimum cBoard tray area
self.min_area = 20000

# callback image
self.cv_image = cv.CreateImage((self.width, self.height), 8, 3)

# colours
self.white = (255, 255, 255)
self.black = (0, 0, 0)

# cBoard tray corners
self.cBoard_tray_corner = [(0.0,0.0),(0.0,0.0),(0.0,0.0),(0.0,0.0)]

# cBoard tray places
# you may choose to use these in the future for the board squares
self.cBoard_tray_place = [(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),
                        (0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0),(0.0,0.0,0.0)]

# Enable the actuators
#baxter_interface.RobotEnable().enable()

# set speed as a ratio of maximum speed -- the default is 0.3. Use this
#self.limb_interface.set_joint_position_speed(0.5)
#self.other_limb_interface.set_joint_position_speed(0.5)

# create image publisher to head monitor
# enable 'latching on the connect means the last message published is saved and sent to any
# future subscribers that connect. This is useful for slow-changing or static data like a map.
self.pub = rospy.Publisher('/robot/xdisplay', Image, latch=True, queue_size=10)

# check if gripper error, if yes, reset
# check if calibrated, if not calibrate the gripper
# grippers do not open and close unless they are calibrated.
if self.gripper.error():  
    self.gripper.reset();  
    print("There was a gripper error, needed reset")
if(not self.gripper.calibrated()):  
    self.gripper.calibrate()  
    print("Calibrated the left gripper")

# display the start splash screen  
self.splash_screen("Chess", "Let's Play")

###
You can access Baxter's two hand cameras and the head camera using the standard ROS image types and image_transport mechanism listed below. You can use the ROS Services to open, close, and configure each of the cameras. See the Camera Control Example and Using the Cameras for more information on using the cameras. Useful tools for using cameras in ROS include rviz and the image_view program. IMPORTANT: You can only have two cameras open at a time at standard resolutions, due to bandwidth limitations. The hand cameras are opened by default at boot-time,

IN THE SIMULATOR, NONE OF THE CAMERA SERVICES WORK--THEREFORE THEY ARE ALL COMMENTED OUT
In order to have the resolution for the simulator camera at 960 and 600, I had to modify baxter_base.gazebo.xacro file. The default is 800 800. If you go to the "gazebo reference = "left_hand_camera" within the document, you will see where you can change the width and height from 800 800 to 960 600 respectively.
Here is the path to the file:
/home/ros_ws/baxter_common/baxter_description/urdf/baxter_base/baxter_base.gazebo.xacro

# reset cameras

###
# when the left camera closed, the power was sent to the right and head cameras
#self.close_camera("left")
#self.close_camera("right")
#now we close the head camera and the power should go back to the right and
# left hand camera
#self.close_camera("head")

# open required camera...in our case it is the left_hand_camera. It should open with
# a resolution of 960, 600. open_camera is a function in this program.
#self.open_camera(self.limb, self.width, self.height)

###
# subscribe to required camera  
self.subscribe_to_camera(self.limb)

###
# distance of arm to table and eBoard tray
self.distance = distance  
#this will be the height down to the board once it is made and depending
# on how thick it is. Remember distances are in meters.
self.tray_distance = distance - 0

###
# move other arm out of harms way
if arm == "left":  
    self.baxter_ik_move("right", (0.25, -0.50, 0.2, math.pi, 0.0, 0.0))
else:  
    self.baxter_ik_move("left", (0.25, 0.50, 0.2, math.pi, 0.0, 0.0))

###
def set_neutral(self):
    print("Moving to neutral pose...")
    self.limb_interface.move_to_neutral()
    self.other_limb_interface.move_to_neutral()

def reset(self):
    print('Resetting picture')
    print("Picture reset")
    img = cv2.imread(self._images + '/default.png')
msg = cv_bridge.CvBridge().cv2_to_imgmsg(img, encoding= "bgr8")
self.pub.publish(msg)

def clean_shutdown(self):
    print("Exiting example...")
    #return to normal
    self.set_neutral()
    rospy.sleep(1)
    self.reset()
    self.gripper.open()
    if not self._init_state:
        print("Disabling robot...")
        self._rs.disable()
    else:
        print("Need to disable robot...")
        self._rs.disable()
    return True

# reset all cameras (incase cameras fail to be recognised on boot)
def reset_cameras(self):
    reset_srv = rospy.ServiceProxy('cameras/reset', std_srvs.srv.Empty)
    rospy.wait_for_service('cameras/reset', timeout=10)
    reset_srv()

    # open a camera and set camera parameters
    #this function needs rework to update
    def open_camera(self, camera, x_res, y_res):
        if camera == "left":
            cam = baxter_interface.camera.CameraController("left_hand_camera")
        elif camera == "right":
            cam = baxter_interface.camera.CameraController("right_hand_camera")
        elif camera == "head":
            cam1 = baxter_interface.camera.CameraController("head_camera")
            cam1.close()
            else:
                sys.exit("ERROR - open_camera - Invalid camera")

    # close camera--comment the next line out because this automatically opens the head camera if
    # you close either the right or left hand camera
    #cam.close()

    # set camera parameters
    cam.resolution = (int(x_res), int(y_res))
    cam.exposure = -1    # range, 0-100 auto = -1
    cam.gain = -1        # range, 0-79 auto = -1
    cam.white_balance_blue = -1  # range 0-4095, auto = -1
    cam.white_balance_green = -1  # range 0-4095, auto = -1
    cam.white_balance_red = -1  # range 0-4095, auto = -1

    # open camera
    cam.open()

    # close a camera
    def close_camera(self, camera):
        if camera == "left":
            cam = baxter_interface.camera.CameraController("left_hand_camera")
        elif camera == "right":
            cam = baxter_interface.camera.CameraController("right_hand_camera")
        elif camera == "head":
            cam = baxter_interface.camera.CameraController("head_camera")
        else:
            sys.exit("ERROR - close_camera - Invalid camera")

    # set camera parameters to automatic
    cam.exposure = -1    # range, 0-100 auto = -1
    cam.gain = -1        # range, 0-79 auto = -1
    cam.white_balance_blue = -1  # range 0-4095, auto = -1
    cam.white_balance_green = -1  # range 0-4095, auto = -1
    cam.white_balance_red = -1  # range 0-4095, auto = -1
# close camera
cam.close()

# convert Baxter point to image pixel
def baxter_to_pixel(self, pt, dist):
    y = (self.height / 2) + int((pt[0] - (self.pose[0] + self.cam_x_offset)) / (self.cam_calib * dist))
    return (x, y)

# convert image pixel to Baxter point
def pixel_to_baxter(self, px, dist):
    x = ((px[1] - (self.height / 2)) * self.cam_calib * dist) + self.pose[0] + self.cam_x_offset
    y = ((px[0] - (self.width / 2)) * self.cam_calib * dist) + self.pose[1] + self.cam_y_offset
    return (x, y)

# Not a tree walk due to python recursion limit
def tree_walk(self, image, x_in, y_in):
    almost_black = (1, 1, 1)
    pixel_list = [(x_in, y_in)]
    # first pixel is black save position
    cv.Set2D(image, y_in, x_in, almost_black)
    # set pixel to almost black
    to_do = [(x_in, y_in - 1)]
    # add neighbours to to do list
    to_do.append([x_in, y_in + 1])
    to_do.append([x_in - 1, y_in])
    to_do.append([x_in + 1, y_in])
    while len(to_do) > 0:
        x, y = to_do.pop()
        # get next pixel to test
        if cv.Get2D(image, y, x)[0] == self.black[0]:
            pixel_list = self.tree_walk(canny, x, y)
            # tree walk pixel
            if len(pixel_list) < self.min_area:
                for l in pixel_list:
                    cv.Set2D(canny, l[1], l[0], self.white)
                    # set pixel to white
            else:
                n = len(pixel_list)
                if n > max_area:
                    sum_x = 0
                    # find centre of object
                    sum_y = 0

# Remove artifacts and find largest object
def look_for_cBoard_tray(self, canny):
    width, height = cv.GetSize(canny)
    centre = (0, 0)
    max_area = 0

    # for all but edge pixels
    for x in range(1, width - 2):
        for y in range(1, height - 2):
            if cv.Get2D(canny, y, x)[0] == self.black[0]:
                # black pixel found
                pixel_list = self.tree_walk(canny, x, y)
                # tree walk pixel
                if len(pixel_list) < self.min_area:
                    # if object too small
                    for i in pixel_list:
                        cv.Set2D(canny, i[1], i[0], self.white)
                else:
                    n = len(pixel_list)
                    if n > max_area:
                        sum_x = 0
                        # find centre of object
                        sum_y = 0

                        # not a tree walk due to python recursion limit
for p in pixel_list:
    sum_x = sum_x + p[0]
    sum_y = sum_y + p[1]

centre = sum_x / n, sum_y / n           # save centre of object
max_area = n                            # save area of object

if max_area > 0:                                             # in tray found
    cv.Circle(canny, (centre), 9, (250, 250, 250), -1)      # mark tray centre

# display the modified canny
cv.ShowImage("Modified Canny", canny)

# 3ms wait
cv.WaitKey(3)
return centre                                        # return centre of object

# flood fill edge of image to leave objects
def flood_fill_edge(self, canny):
    width, height = cv.GetSize(canny)

    # set boarder pixels to white
    for x in range(width):
        cv.Set2D(canny, 0, x, self.white)
        cv.Set2D(canny, height - 1, x, self.white)
    for y in range(height):
        cv.Set2D(canny, y, 0, self.white)
        cv.Set2D(canny, y, width - 1, self.white)

    # prime to do list
    to_do = [(2, 2)]
    to_do.append([2, height - 3])
    to_do.append([width - 3, height - 3])
    to_do.append([width - 3, 2])

    while len(to_do) > 0:
        x, y = to_do.pop()                               # get next pixel to test
        if cv.Get2D(canny, y, x)[0] == self.black[0]:    # if black pixel found
            cv.Set2D(canny, y, x, self.white)            # set pixel to white
            to_do.append([x, y - 1])                     # add neighbours to to do list
            to_do.append([x, y + 1])
            to_do.append([x - 1, y])
            to_do.append([x + 1, y])

# camera call back function
# consider changing the callback function to only take the data.
def camera_callback(self, data, camera_name):
    try:
        # using ROS cv_bridge to convert the image to a CV image.
        # go to the web page: http://wiki.ros.org/cv_bridge/Tutorials/ConvertingBetweenROSImagesAndOpenCVImagesPython
        # there is a tutorial there
        # data is the image that is coming from the rostopic via the hand_camera
        self.cv_image = cv_bridge.CvBridge().imgmsg_to_cv2(data, "bgr8")
    except cv_bridge.CvBridgeError, e:
        print e

    # 3ms wait --wait for 3 milliseconds
    cv.WaitKey(3)

# left camera call back function
# not sure why we need the second parameter
# consider changing camera_callback function so that it only takes just the data
def left_camera_callback(self, data):
    self.camera_callback(data, "Left Hand Camera")

# right camera call back function
def right_camera_callback(self, data):
# head camera call back function
def head_camera_callback(self, data):
    self.camera_callback(data, "Head Camera")

# create subscriber to the required camera
# this is one of Baxter’s topic. When a topic is subscribed to
# there must be a callback function.
def subscribe_to_camera(self, camera):
    if camera == "left":
        callback = self.left_camera_callback
        camera_str = "/cameras/left_hand_camera/image"
    elif camera == "right":
        callback = self.right_camera_callback
        camera_str = "/cameras/right_hand_camera/image"
    elif camera == "head":
        callback = self.head_camera_callback
        camera_str = "/cameras/head_camera/image"
    else:
        sys.exit("ERROR - subscribe_to_camera - Invalid camera")
    camera_sub = rospy.Subscriber(camera_str, Image, callback)

# Convert cv image to a numpy array
def cv2array(self, im):
    depth2dtype = {cv.IPL_DEPTH_8U: 'uint8",
                   cv.IPL_DEPTH_8S: 'int8",
                   cv.IPL_DEPTH_16U: 'uint16",
                   cv.IPL_DEPTH_16S: 'int16",
                   cv.IPL_DEPTH_32S: 'int32",
                   cv.IPL_DEPTH_32F: 'float32",
                   cv.IPL_DEPTH_64F: 'float64'
                   }
    arrdtype = im.depth
    a = numpy.fromstring(im.tostring(),
                         dtype = depth2dtype[im.depth],
                         count = im.width * im.height * im.nChannels)
    a.shape = (im.height, im.width, im.nChannels)
    return a

# the original code imported conversions from moveit commander in the header.
# This caused an error only on shut down---did not affect the program. Rather than deal with errors
# even at shut down while you are trying to implement code, I went to
# web site below and copied and pasted the two needed function here with
# slight modification only in the except line where you print "Unexpected error"
# https://github.com/ros-planning/moveit/blob/kinetic-devel/moveit_commander/src/moveit_commander/conversions.py
# These functions create the PoseStamped msgs needed for the ik service.

def list_to_pose(self, pose_list):
    try:
        if len(pose_list) == 7:
            pose_msg.position.x = pose_list[0]
            pose_msg.position.y = pose_list[1]
            pose_msg.position.z = pose_list[2]
            pose_msg.orientation.x = pose_list[3]
            pose_msg.orientation.y = pose_list[4]
            pose_msg.orientation.z = pose_list[5]
            pose_msg.orientation.w = pose_list[6]
        elif len(pose_list) == 6:
            pose_msg.position.x = pose_list[0]
            pose_msg.position.y = pose_list[1]
            pose_msg.position.z = pose_list[2]
            q = tf.transformations.quaternion_from_euler(pose_list[3], pose_list[4], pose_list[5])
            pose_msg.orientation.x = q[0]
            pose_msg.orientation.y = q[1]
            pose_msg.orientation.z = q[2]
def list_to_pose_stamped(self, pose_list, target_frame):
    pose_msg = PoseStamped()
    pose_msg.pose = self.list_to_pose(pose_list)
    pose_msg.header.frame_id = target_frame
    pose_msg.header.stamp = rospy.Time.now()
    return pose_msg

# move a limb
def baxter_ik_move(self, limb, rpy_pose):
    quaternion_pose = self.list_to_pose_stamped(rpy_pose, "base")
    #quaternion_pose = conversions.list_to_pose_stamped(rpy_pose, "base")
    node = "ExternalTools/" + limb + "/PositionKinematicsNode/IKService"
    ik_service = rospy.ServiceProxy(node, SolvePositionIK)
    ik_request = SolvePositionIKRequest()
    hdr = Header(stamp=rospy.Time.now(), frame_id="base")

    ik_request.pose_stamp.append(quaternion_pose)

    try:
        rospy.wait_for_service(node, 5.0)
        ik_response = ik_service(ik_request)
        except (rospy.ServiceException, rospy.ROSException), error_message:
            rospy.logerr("Service request failed: %r" % (error_message,))
            sys.exit("ERROR - baxter_ik_move - Failed to append pose")
    if ik_response.isValid[0]:
        #self.splash_screen("Valid", "move")
        print("PASS: Valid joint configuration found")
        # convert response to joint position control dictionary
        limb_joints = dict(zip(ik_response.joints[0].name, ik_response.joints[0].position))
        # move limb
        if self.limb == limb:
            self.limb_interface.move_to_joint_positions(limb_joints)
        else:
            self.other_limb_interface.move_to_joint_positions(limb_joints)
    else:
        # display invalid move message on head display
        #self.splash_screen("Invalid", "move")
        # little point in continuing so exit with error message
        print("Requested move not valid")
        #this will try 3 more times to see if the requested move has a valid solution
        if limb == 'left':
            # requesting the starting position again for this program--will need a better solution
            self.pose = (self.cBoard_tray_x, self.cBoard_tray_y, self.cBoard_tray_z, self.roll, self.pitch, self.yaw)
            self.baxter_ik_move(self.limb, self.pose)
            #return False
            #sys.exit("ERROR - baxter_ik_move - No valid joint configuration found")
        else:
            #self.baxter_ik_move("right", (0.25, -0.50, 0.2, math.pi, 0.0, 0.0))
            print("moving right arm out of the way")
            self.other_limb_interface.move_to_joint_positions(self.starting_right_joint_angles)

if self.limb == limb:  # if working arm
    ......
The package baxter_interface is found at api.rethinkrobotics.com/baxter_interface/html/index.html

In the limb class, the functions are described.

`endpoint_pose()` returns the Cartesian endpoint pose {position, orientation}. tf (transform frame) of the gripper

All measurements reported for the endpoint (pose, twist, and wrench) are with respect to the /base frame of the robot.

`pose = {'position': (x,y,z), 'orientation': (x,y,z,w)}`

Therefore, for the line of code that says `position = quaternion_pose['position']`,

this means that `position = [(x,y,z)]` of the `endpoint_pose`

```
quaternion_pose = self.limb_interface.endpoint_pose()
position = quaternion_pose['position']
```

# if working arm remember actual (x,y) position achieved
# if Baxter's left arm reached the coordinates over the board that we want,
# we are saving those x and y positions. This is why we are using the x and y
# from position above.
self.pose = (position[0], position[1],
    self.pose[2], self.pose[3], self.pose[4], self.pose[5])

# update pose in x and y direction
def update_pose(self, dx, dy):
    x = self.pose[0] + dx
    y = self.pose[1] + dy
    pose = [x, y, self.pose[2], self.roll, self.pitch, self.yaw]
    self.baxter_ik_move(self.limb, pose)

# used to place camera over the cBoard tray
def cBoard_tray_iterate(self, iteration, centre):
    # print iteration number
    print "Egg Tray Iteration ", iteration
    # find displacement of object from centre of image
    pixel_dx = (self.width / 2) - centre[0]
    pixel_dy = (self.height / 2) - centre[1]
    pixel_error = math.sqrt((pixel_dx * pixel_dx) + (pixel_dy * pixel_dy))
    error = float(pixel_error * self.cam_calib * self.tray_distance)
    print("Here is the error: ", error)
    print("Here is the self.tray_tolerance: ", self.tray_tolerance)
    x_offset = -pixel_dy * self.cam_calib * self.tray_distance
    y_offset = -pixel_dx * self.cam_calib * self.tray_distance
    if error > self.tray_tolerance:
        # correct pose
        self.update_pose(x_offset, y_offset)
        # find new centre
        centre = self.canny_it(iteration)
    # find displacement of object from centre of image
    pixel_dx = (self.width / 2) - centre[0]
    pixel_dy = (self.height / 2) - centre[1]
    pixel_error = math.sqrt((pixel_dx * pixel_dx) + (pixel_dy * pixel_dy))
    error = float(pixel_error * self.cam_calib * self.tray_distance)
    return centre, error

# randomly adjust a pose to dither arm position
# used to prevent stalemate when looking for cBoard tray
# the numbers generated will be floats between 0.0 to 1.0
def dither(self):
    x = self.cBoard_tray_x
    y = self.cBoard_tray_y + (random.random() / 10.0)
    pose = (x, y, self.cBoard_tray_z, self.roll, self.pitch, self.yaw)
    return pose

# find the cBoard tray
def canny_it(self, iteration):
    if self.save_images:
        # save raw image of cBoard tray
        file_name = self.image_dir + "board_" + str(iteration) + ".jpg"
        cv.SaveImage(file_name, cv.fromarray(self.cv_image))
        width, height = cv.GetSize(cv.fromarray(self.cv_image))
        print("Here is the width: {} and here is the height: {}.").format(width, height)

        # create an empty image variable, the same dimensions as our camera feed.
        gray = cv.CreateImage((cv.GetSize(cv.fromarray(self.cv_image))), 8, 1)

        # convert the image to a grayscale image
        cv.CvtColor(cv.fromarray(self.cv_image), gray, cv.CV_BGR2GRAY)

        # display image on head monitor
        font = cv.InitFont(cv.CV_FONT_HERSHEY_SIMPLEX, 1.0, 1.0, 1)
        position = (30, 60)
        cv.PutText(cv.fromarray(self.cv_image), "Looking for Chess Board", position, font, self.white)
        msg = cv_bridge.CvBridge().cv2_to_imgmsg(self.cv_image, encoding="bgr8")
        self.pub.publish(msg)

        # create a Trackbar for user to enter threshold
        #The info can be obtained on github by Atlas7/opencv_python_tutorials.
        # he shows how to create a tracker bar to adjust the greyscale thresholds
        # http://mathalope.co.uk/2015/06/03/canny-edge-detection-app-with-opencv-python/
        # create a canny edge detection map of the grayscale image
        cv.Canny(gray, self.canny, self.canny_low, self.canny_high, 3)

        # display the canny transformation
        cv.ShowImage("Canny Edge Detection", self.canny)

        if self.save_images:
            # save Canny image of cBoard tray
            file_name = self.image_dir + "canny_tray_" + str(iteration) + ".jpg"
            cv.SaveImage(file_name, self.canny)

            # flood fill edge of image to leave only objects
            self.flood_fill_edge(self.canny)

            cBoard_tray_centre = self.look_for_cBoard_tray(self.canny)

            # 3ms wait
            cv.WaitKey(3)

            while cBoard_tray_centre[0] == 0:
                if random.random() > 0.6:
                    self.baxter_ik_move(self.limb, self.dither())

            cBoard_tray_centre = self.canny_it(iteration)
            print("Here are the coordinates of cBoard_tray_centre: ", cBoard_tray_centre)
            return cBoard_tray_centre

    def find_places(self, c):
        # find long side of cBoard tray
        cc = [c[0], c[1], c[2], c[3]]

        # cBoard tray corners in baxter coordinates
        for i in range(4):
            self.cBoard_tray_corner[i] = self.pixel_to_baxter(cc[i], self.tray_distance)

        # cBoard tray places in pixel coordinates
        ref_x = cc[0][0]
        ref_y = cc[0][1]
        dl_x = (cc[1][0] - cc[0][0]) / 8
        dl_y = (cc[1][1] - cc[0][1]) / 8
        ds_x = (cc[2][0] - cc[1][0]) / 8
        ds_y = (cc[2][1] - cc[1][1]) / 8

        # please see the diagram with the map of the functions location and how
Correlate to the colors. The order below is different than that of the original.

```python
p = {}
tempcount = 0
for i in range(8):
    for j in range(8):
        p[tempcount] = (ref_x + ((8-i+.7) * dl_x) + ((j+.7) * ds_x), ref_y + ((8-i-.4) * dl_y) + ((j-1-.4) * ds_y))
        tempcount = tempcount + 1

p[64] = (p[31][0]+100, p[31][1])
p[65] = (p[28][0]-20, p[28][1] + 20)
for i in range(66):
    # mark position of cBoard tray places --- different colors were used so you could correlate what the calculations above are doing.
    # parameters are img, center, radius, circle color(bgr for lime green is (0,250,0)), -1 means that it will fill the shape
    cv.Circle(cv.fromarray(self.cv_image), (int(p[i][0]), int(p[i][1])), 5, (0, 255, 0), -1)
    self.cBoard_tray_place[i] = self.pixel_to_baxter(p[i], self.tray_distance)
```

Display the cBoard tray places

```python
if self.save_images:
    # save cBoard tray image with overlay of cBoard tray and cBoard positions
    file_name = self.image_dir + "chess_board.jpg"
    cv.SaveImage(file_name, cv.fromarray(self.cv_image))
    # 3ms wait
    cv.WaitKey(3)
```

Find four corners of the cBoard tray

```python
def find_corners(self, centre):
    self.center = centre
    # find bottom corner
    max_x = 0
    max_y = 0
    for x in range(100, self.width -100):
        y = self.height - 20
        #array, index1, index2
        while y > 0 and cv.Get2D(self.canny, y, x)[0] > 100:
            y = y - 1
        if y > 20:
            cv.Set2D(cv.fromarray(self.cv_image), y, x, (255, 0, 0)) #red is bgr(0,0,255)
            if y > max_y:
                max_x = x
                max_y = y

    corner_1 = (max_x, max_y)
    # find left corner
    min_x = self.width
    min_y = 0
    for y in range(100, self.height - 100):
        x = 20
        while x < self.width - 1 and cv.Get2D(self.canny, y, x)[0] > 100:
            x = x + 1
        if x < self.width - 20:
            cv.Set2D(cv.fromarray(self.cv_image), y, x, (0, 255, 0))
            if y < min_y:
                min_x = x
                min_y = y

    corner_2 = (min_x, min_y)
```

Display corner image

```python
cv.ShowImage("Corner", cv.fromarray(self.cv_image))
```
if self.save_images:
    # save Canny image
    file_name = self.image_dir + "board_canny.jpg"
    cv.SaveImage(file_name, self.canny)

    # mark corners and save corner image
    cv.Circle(cv.fromarray(self.cv_image), corner_1, 9, (0, 0, 255)
    cv.Circle(cv.fromarray(self.cv_image), corner_2, 9, (0, 255, 0)
    file_name = self.image_dir + "corner.jpg"
    cv.SaveImage(file_name, cv.fromarray(self.cv_image))

    # 3ms wait
    cv.WaitKey(3)

# two corners found and centre known find other two corners
corner_3 = ((2 * centre[0]) - corner_1[0], (2 * centre[1]) - corner_1[1])
corner_4 = ((2 * centre[0]) - corner_2[0], (2 * centre[1]) - corner_2[1])

if self.save_images:
    # save Canny image
    file_name = self.image_dir + "board_canny.jpg"
    cv.SaveImage(file_name, self.canny)

    # mark corners and save corner image
    cv.Circle(cv.fromarray(self.cv_image), corner_1, 9, (0, 0, 255)
    cv.Circle(cv.fromarray(self.cv_image), corner_2, 9, (0, 255, 0)
    cv.Circle(cv.fromarray(self.cv_image), corner_3, 9, (255, 0, 0)
    cv.Circle(cv.fromarray(self.cv_image), corner_4, 9, (255, 255, 0)
    file_name = self.image_dir + "all_four_corners.jpg"
    cv.SaveImage(file_name, cv.fromarray(self.cv_image))

# draw cBoard tray boundry
    c1 = (int(corner_1[0]), int(corner_1[1]))
    c2 = (int(corner_2[0]), int(corner_2[1]))
    c3 = (int(corner_3[0]), int(corner_3[1]))
    c4 = (int(corner_4[0]), int(corner_4[1]))

    cv.Line(cv.fromarray(self.cv_image), c1, c2, (255, 0, 0), thickness=3)
    cv.Line(cv.fromarray(self.cv_image), c2, c3, (0, 255, 0), thickness=3)
    cv.Line(cv.fromarray(self.cv_image), c3, c4, (255, 255, 0), thickness=3)
    cv.Line(cv.fromarray(self.cv_image), c4, c1, (0, 0, 255), thickness=3)

    return True, (corner_1, corner_2, corner_3, corner_4)

# find the cBoard tray
def find_cBoard_tray(self):
    # define and initialize boolean variable named ok
    ok = False
    # while ok is false
    while not ok:
        cBoard_tray_centre = self.canny_it(0)
        error = 2 * self.tray_tolerance
        iteration = 1

        # iterate until arm over centre of tray
        while error > self.tray_tolerance:
            cBoard_tray_centre, error = self.cBoard_tray_iterate(iteration
            iteration += 1

        # find cBoard tray corners in pixel units
        (ok, corners) = self.find_corners(cBoard_tray_centre)

        self.find_places(corners)

    # display message on head display
    def splash_screen(self, s1, s2):
        splash_array = numpy.zeros((self.height, self.width, 3), numpy.uint8)
font = cv.InitFont(cv.CV_FONT_HERSHEY_SIMPLEX, 3.0, 3.0, 9)

((text_x, text_y), baseline) = cv.GetTextSize(s1, font)
org = ((self.width - text_x) / 2, (self.height / 3) + (text_y / 2))
cv2.putText(splash_array, s1, org, cv.CV_FONT_HERSHEY_SIMPLEX, 3.0,
    self.white, thickness = 7)

((text_x, text_y), baseline) = cv.GetTextSize(s2, font)
org = ((self.width - text_x) / 2, ((2 * self.height) / 3) + (text_y / 2))
cv2.putText(splash_array, s2, org, cv.CV_FONT_HERSHEY_SIMPLEX, 3.0,
    self.white, thickness = 7)
splash_image = cv.fromarray(splash_array)

# 3ms wait
cv2.waitKey(3)

msg = cv_bridge.CvBridge().cv2_to_imgmsg(splash_array, encoding="bgr8")
self.pub.publish(msg)

def find_offset_pose(self, pose):
    pose1 = copy.deepcopy(pose)
    print("Here is the pose coming into find_offset_pose: ", pose1)
    list_of_circles = []
    file_name = self.image_dir + "circles" + ".jpg"
    cv.SaveImage(file_name, cv.fromarray(self.cv_image))
    image = cv2.imread(file_name)
    cv2.imshow("Test Circle", image)
    cv2.waitKey(0)
    gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)
    blurred = cv2.GaussianBlur(gray, (5,5),0)
    thresh = cv2.threshold(blurred,40, 255, cv2.THRESH_BINARY)[1]
    #cv2.imshow("Threshold Picture", thresh)
    thresh = cv2.bitwise_not(thresh)
    #cv2.imshow("Threshold Inverted", thresh)
    #find contours in the threshold image
    cnts = cv2.findContours(thresh.copy(), cv2.RETR_EXTERNAL, 
        cv2.CHAIN_APPROX_SIMPLE)
    cnts = cnts[0] if imutils.is_cv2() else cnts[1]

circle_centers = []
closest_point = (0,0)
distance = 10000.00
length = len(cnts)
print("The length of cnts is: ", length)
print("a" * 2)
# loop over the contours
for c in cnts:
    # compute the center of the contour
    point = (0,0)
    M = cv2.moments(c)
    #print("The moments")
    #print(M)
    if M["m00"] == 0:
        print("****************")
        print("M[m00] equaled 0")
        print("***************")
        print("["m00] equaled 0")
        print("***************")
    else:
        cX = int(M["m10"] / M["m00"])  
cY = int(M["m01"] / M["m00"])  
#shape = self.sd.detect(c)
#print("Here is the value of shape: ", shape)
    center = str(cX) + "," + str(cY)
    point = cX, cY
    print("Here is the value of point: ", point)
    #convert to baxter coordinates.
cBoard = self.pixel_to_baxter_close(point, .153)
# find distance between center where contour found and desired pose.

print("Before Distance calculation")
distance_new = ((cBoard[0] - pose[0]) * (cBoard[0] - pose[0])) + ((cBoard[1] - pose[1]) * (cBoard[1] - pose[1]))
print("After Distance Calculation")
if distance_new < distance:
distance = distance_new
closest_point = cBoard[0], cBoard[1]

center = str(cBoard[0]) +", " + str(cBoard[1])
print("Here is the value of cBoard after change to pixel_to_baxter: ", cBoard)
circle_centers.append(cBoard)
print("Here is the value of circle_centers in the for-loop: ", circle_centers)
print('n' * 2)

# draw the contour and center of the shape on the image
cv2.drawContours(image, [c], -1, (0, 255, 0), 2)
cv2.circle(image, (cX, cY), 7, (255, 255, 255), -1)
# cv2.putText(image, center, (cX - 20, cY - 20), cv2.FONT_HERSHEY_SIMPLEX, 0.5, (255, 0, 0), 2)
# show the image
cv2.imshow("Image", image)
# cv2.waitKey(0)
print("Here is the value of the closest point outside the for-loop: ", closest_point)
# calculate the offsets from where you want to go to where the actual contour is located.

pose1[0] = closest_point[0]
pose1[1] = closest_point[1]

print("The updated version of pose1: ", pose1)
return pose1

def gripper_open(self):
    self.gripper.open()
    rospy.sleep(1.0)

def gripper_close(self):
    self.gripper.close()
    rospy.sleep(1.0)

def _approach(self, pose):
    pose1 = copy.deepcopy(pose)

    # approach with a pose the hover-distance above the requested pose
    self.baxter_ik_move(self.limb, pose1)

def _retract(self):
    # retrieve current pose from endpoint
    current_pose = self.limb_interface.endpoint_pose()
    ik_pose = []
    ik_pose.append(current_pose['position'][0])
    ik_pose.append(current_pose['position'][1])
    ik_pose.append(current_pose['position'][2] + self._hover_distance)
    ik_pose.append(current_pose['orientation'][0])
    ik_pose.append(current_pose['orientation'][1])
    ik_pose.append(current_pose['orientation'][2])
    ik_pose.append(current_pose['orientation'][3])
    self.baxter_ik_move(self.limb, ik_pose)

    # servo up from current pose

def _servo_to_pose(self, pose):
    # servo down to release
    self.baxter_ik_move(self.limb, pose)

def pick(self, pose):
# open the gripper
self.gripper_open()

# servo above pose
self._approach(pose)

    pose_offset = self.find_offset_pose(pose)
    self._approach(pose_offset)

# servo to pose
self._servo_to_pose(pose_offset)

# close gripper
self.gripper_close()

# retract to clear object
self._retract()

def middle(self, pose):
    self._approach(pose)

def place(self, pose):
    self._approach(pose)
    self._servo_to_pose(pose)
    self.gripper_open()
    self._retract()

# END OF CLASS LOCATOR

# read the setup parameters from setup.dat
# This is the first function to look at. It is entirely
# optional. The limb and distance can be "hard coded" or
# you can even get user input if desired.
def get_setup():
    global image_directory
    file_name = image_directory + "setup.dat"

    try:
        f = open(file_name, "r")
    except ValueError:
        sys.exit("ERROR: setup must be run before this")

    # find limb
    s = string.split(f.readline())
    if len(s) >= 3:
        if s[2] == "left" or s[2] == "right":
            limb = s[2]
        else:
            sys.exit("ERROR: invalid limb in %s" % file_name)
    else:
        sys.exit("ERROR: missing limb in %s" % file_name)

    # find distance to table
    s = string.split(f.readline())
    if len(s) >= 3:
        try:
            distance = float(s[2])
        except ValueError:
            sys.exit("ERROR: invalid distance in %s" % file_name)
        else:
            sys.exit("ERROR: missing distance in %s" % file_name)

    return limb, distance

# this function loads the models used in gazebo
def load_gazebo_models(table_pose=Pose(position=Point(x=.75, y=0.2, z=0.0)),
    table_reference_frame="world").
block_pose=Pose(position=Point(x=0.6, y=0.25, z=0.7825)),
block_reference_frame="world"):
# Get Models' Path
model_path = rospkg.RosPack().get_path('baby_steps') + "/models/"
# Load Table SDF
table_xml = "
with open (model_path + "cafe_table/model.sdf", "r") as table_file:
    table_xml=table_file.read().replace("\n", "")
# Load Block URDF
block_xml = "
with open (model_path + "block/chessboard.sdf", "r") as block_file:
    block_xml=block_file.read().replace("\n", "")
# Spawn Table SDF
rospy.wait_for_service("/gazebo/spawn_sdf_model")
try:
    spawn_sdf = rospy.ServiceProxy("/gazebo/spawn_sdf_model", SpawnModel)
    resp_sdf = spawn_sdf("cafe_table", table_xml, "/",
                   table_pose, table_reference_frame)
except rospy.ServiceException, e:
    rospy.logerr("Spawn SDF service call failed: {0}".format(e))
# Spawn Block URDF
rospy.wait_for_service("/gazebo/spawn_sdf_model")
try:
    spawn_sdf = rospy.ServiceProxy("/gazebo/spawn_sdf_model", SpawnModel)
    resp_sdf = spawn_sdf("cafe_table", table_xml, "/",
                   table_pose, table_reference_frame)
except rospy.ServiceException, e:
    rospy.logerr("Spawn SDF service call failed: {0}".format(e))
def delete_gazebo_models():
    # This will be called on ROS Exit, deleting Gazebo models
    # Do not wait for the Gazebo Delete Model service, since
    # Gazebo should already be running. If the service is not
    # available since Gazebo has been killed, it is fine to error out
    try:
        delete_model = rospy.ServiceProxy("/gazebo/delete_model", DeleteModel)
        resp_delete = delete_model("cafe_table")
        resp_delete = delete_model("block")
        except rospy.ServiceException, e:
            rospy.loginfo("Delete Model service call failed: {0}".format(e))

Files Utilized, Modified, and Developed by Zephaniah Connell

pyttsx_server.py
#!/usr/bin/env python
# Please see the license.txt file for the open source licenses for these two references
""
References:
"Programming Robots with ROS" by Morgan Quigley, Brian Gerkey, and William Smart. Chapter 19 is devoted to making the robot talk using pyttsx. Pyttsx is text to speech. Code was used from the book. The code for the book is available at (i) and the documentation for pyttsx is available at (ii)
(i) https://github.com/osrf/rosbook
Reference for implementing a simple action server is from the ROS Wiki Tutorial Web site:
""
import rospy
import threading, time, pyttsx
import actionlib
from baby_steps.msg import TalkAction, TalkGoal, TalkResult
class TalkNode():
    def __init__(self, node_name, action_name):
        rospy.init_node(node_name, anonymous = True)
#first create a simple action server. Arguments are a name, an action, a call_back, and set auto_start to False
self.server = actionlib.SimpleActionServer(action_name, TalkAction, self.do_talk, False)

#get a reference to an engine reference from the pyttsx library
self.engine = pyttsx.init()

""
In the next section, we declare a variable used to set the properties for the robot voice we will be setting the rate which is integer speech rate in words per minute.
voices is a list of the available "voices" in pyttsx. We will be using id 16.
We also start a thread to run the speech engine loop
""
rate = self.engine.getProperty('rate')
voices = self.engine.getProperty('voices')
self.engine_thread = threading.Thread(target=self.loop)
self.engine_thread.start()
self.engine.setProperty('volume', rospy.get_param('~volume', 1.0))
self.engine.setProperty('rate', rate - 90)
self.engine.setProperty('voice', voices[16].id)
self.preempt = rospy.get_param('~preempt', False)

#start the action server
self.server.start()

def loop(self):
    self.engine.startLoop(False)
    while not rospy.is_shutdown():
        # when using an external event loop, engine.iterate must be used within the external loop per pyttsx docs
        self.engine.iterate()
        time.sleep(0.1)
    self.engine.endLoop()

def do_talk(self, goal):
    # when the server receives a goal to speak, it passes it to the speech engine we created.
    self.engine.say(goal.sentence)
    while self.engine.isBusy():
        # action servers allow the action to be preempted. If a request is received then the action would be stopped by using
        # the speech libraries stop function for the engine we created.
        if self.preempt and self.server.is_preempt_requested():
            self.engine.stop()
            while self.engine.isBusy():
                time.sleep(0.1)
            self.server.set_preempted(TalkResult(), "Talk preempted")
            return
        time.sleep(0.1)
    self.server.set_succeeded(TalkResult(), "Talk completed successfully")

# create an instance of the TalkNode class
talker = TalkNode('speaker', 'speak')

# keep the server spinning
rospy.spin()
import rospy
import actionlib
from baby_steps.msg import TalkAction, TalkGoal, TalkResult

class Talk:
    def say_something(self, what_to_say):
        #rospy.init_node('speaker_client')
        #create the client by passing in as arguments the name and type of action
        #in this case, we are using the TalkAction.action that we created
        client = actionlib.SimpleActionClient('speak', TalkAction)
        #we wait until the action server has started and is accepting goals
        client.wait_for_server()
        #TalkGoal was created when we wrote the Talk.action file and then compiled it
        # In Talk.action, we define the goal as string sentence. Thus the data type
        # is a string and the goal is sentence
        goal = TalkGoal()
        goal.sentence = what_to_say
        #send the goal to the action server. In this case, the goal is to say our sentence.
        client.send_goal(goal)
        #wait for the server to give us our results.
        client.wait_for_result()
        print('[Result] State: %d'%(client.get_state()))
        print('[Result] Status: %s'%(client.get_goal_status_text()))

if __name__ == '__main__':
    try:
        rospy.init_node('speaker_client', anonymous = True)
        talk1 = Talk()
        talk1.talk_client()
        #talk1=talk_client()
    except rospy.ROSInterruptException:
        print "program interrupted before completion"

voicecommands.py
#!/usr/bin/env python
import baxter_interface
from baxter_interface import CHECK_VERSION
import rospy
from std_msgs.msg import (String,
Float64,
)
import ros pkg

import game = Game()
game.create_piece_dict()
game.print_board()

import locate
import string
import copy
import os
image_directory = os.getenv("HOME") + "\Golf\"

import reset
import copy
import os
image_directory = os.getenv("HOME") + "\Golf\"

# import class for text to speech
from pyttsx_client import Talk

class Voice:
    def __init__(self):
        rs = baxter_interface.RobotEnable(CHECK_VERSION)
        print("Enabling robot... ")
        rs.enable()

        self.rate = 5
        self.r = rospy.Rate(self.rate)

        self.message = 'nothing yet'

        # A flag to determine whether or not voice control is paused
        self.paused = True

        # A flag to determine if the given command is the pickup index or placement index
        self.movementdefined = False

        # variables for the starting and ending positions
        self.piecetomove = 'none'
        self.destination = 'nowhere'

        # variable to determine whose turn it is
        self.whiteturn = True

        # variables to determine if Baxter successfully executed a move if valid
        self.checkedmove = False
        self.waitingforcheck = False
        self.movesuccess = False

        # variable to determine if a chess piece movement has been successfully requested
        self.movementdefined = False

        # Subscribe to the /recognizer/output topic to receive voice commands.
        rospy.Subscriber('/recognizer/output', String, self.speech_callback)

        # Object to be used for text to speech
        self.talk = Talk()

    def speech_callback(self, msg):
        # Get the motion command from the recognized phrase
        command = msg.data

        # Log the command to the screen
        rospy.loginfo("Command: " + str(command))

        # If the user has asked to pause/continue voice control,
        # set the flag accordingly
        if command == 'pause':
            self.paused = True

            what_to_say = "Voice command features disabled."
            self.talk.say_something(what_to_say)
            print(what_to_say)

            return

        elif command == 'continue':
            self.paused = False

            what_to_say = "Voice command features enabled."
            self.talk.say_something(what_to_say)
            print(what_to_say)

            return

        # If voice control is paused, simply return without
        # performing any action
        if self.paused:
            what_to_say = "Currently paused"

            #self.talk.say_something(what_to_say)
print(what_to_say)
return

if command == 'shutdown':
    #reset = Reset()
    #reset.set_neutral()
    #reset.reset_facescreen()
    #reset.grippers_reset()
    #reset.disable_motors()
    rospy.signal_shutdown('Quit')
    what_to_say = "Baxter's arms now in neutral position, led display back to rethink log and motors have been disabled."
    self.talk.say_something(what_to_say)
    print(what_to_say)
    return

    # wait for an answer to whether Baxter successfully made a move or not before accepting any new movements
    if self.movementdefined and not self.checkedmove:
        if command == 'success':
            self.checkedmove = True
            self.movesuccess = True
        elif command == 'failure':
            self.checkedmove = True
            self.movesuccess = False
        else:
            self.paused = True
            what_to_say = "Must answer before requesting another move. Did Baxter successfully make the move most recently requested? Reply 'Success' or 'Failure'."
            self.talk.say_something(what_to_say)
            print(what_to_say)
            self.paused = False
            return

    piece = 'none'
    index = 'nowhere'

    # get index of piece to move or index to move to
    if command == 'alpha one':
        index = 'a1'
    elif command == 'alpha two':
        index = 'a2'
    elif command == 'alpha three':
        index = 'a3'
    elif command == 'alpha four':
        index = 'a4'
    elif command == 'alpha five':
        index = 'a5'
    elif command == 'alpha six':
        index = 'a6'
    elif command == 'alpha seven':
        index = 'a7'
    elif command == 'alpha eight':
        index = 'a8'
    elif command == 'bravo one':
        index = 'b1'
    elif command == 'bravo two':
        index = 'b2'
    elif command == 'bravo three':
        index = 'b3'
    elif command == 'bravo four':
        index = 'b4'
    elif command == 'bravo five':
        index = 'b5'
    elif command == 'bravo six':
        index = 'b6'
    elif command == 'bravo seven':
        index = 'b7'
    elif command == 'bravo eight':
        index = 'b8'
    elif command == 'charlie one':
        index = 'c1'
elif command == 'charlie two':
    index = 'c2'
elif command == 'charlie three':
    index = 'c3'
elif command == 'charlie four':
    index = 'c4'
elif command == 'charlie five':
    index = 'c5'
elif command == 'charlie six':
    index = 'c6'
elif command == 'charlie seven':
    index = 'c7'
elif command == 'charlie eight':
    index = 'c8'
elif command == 'delta one':
    index = 'd1'
elif command == 'delta two':
    index = 'd2'
elif command == 'delta three':
    index = 'd3'
elif command == 'delta four':
    index = 'd4'
elif command == 'delta five':
    index = 'd5'
elif command == 'delta six':
    index = 'd6'
elif command == 'delta seven':
    index = 'd7'
elif command == 'delta eight':
    index = 'd8'
elif command == 'echo one':
    index = 'e1'
elif command == 'echo two':
    index = 'e2'
elif command == 'echo three':
    index = 'e3'
elif command == 'echo four':
    index = 'e4'
elif command == 'echo five':
    index = 'e5'
elif command == 'echo six':
    index = 'e6'
elif command == 'echo seven':
    index = 'e7'
elif command == 'echo eight':
    index = 'e8'
elif command == 'foxtrot one':
    index = 'f1'
elif command == 'foxtrot two':
    index = 'f2'
elif command == 'foxtrot three':
    index = 'f3'
elif command == 'foxtrot four':
    index = 'f4'
elif command == 'foxtrot five':
    index = 'f5'
elif command == 'foxtrot six':
    index = 'f6'
elif command == 'foxtrot seven':
    index = 'f7'
elif command == 'foxtrot eight':
    index = 'f8'
elif command == 'golf one':
    index = 'g1'
elif command == 'golf two':
    index = 'g2'
elif command == 'golf three':
    index = 'g3'
elif command == 'golf four':
    index = 'g4'
elif command == 'golf five':
    index = 'g5'
elif command == 'golf six':
    index = 'g6'
elif command == 'golf seven':
    index = 'g7'
elif command == 'golf eight':
    index = 'g8'
elif command == 'hotel one':
    index = 'h1'
elif command == 'hotel two':
    index = 'h2'
elif command == 'hotel three':
    index = 'h3'
elif command == 'hotel four':
    index = 'h4'
elif command == 'hotel five':
    index = 'h5'
elif command == 'hotel six':
    index = 'h6'
elif command == 'hotel seven':
    index = 'h7'
elif command == 'hotel eight':
    index = 'h8'
elif command == 'pawn one':
    piece = 'P1'
elif command == 'pawn two':
    piece = 'P2'
elif command == 'pawn three':
    piece = 'P3'
elif command == 'pawn four':
    piece = 'P4'
elif command == 'pawn five':
    piece = 'P5'
elif command == 'pawn six':
    piece = 'P6'
elif command == 'pawn seven':
    piece = 'P7'
elif command == 'pawn eight':
    piece = 'P8'
elif command == 'rook one':
    piece = 'R1'
elif command == 'rook two':
    piece = 'R2'
elif command == 'knight one':
    piece = 'N1'
elif command == 'knight two':
    piece = 'N2'
elif command == 'bishop one':
    piece = 'B1'
elif command == 'bishop two':
    piece = 'B2'
elif command == 'king':
    piece = 'K'
elif command == 'queen':
    piece = 'Q'
elif command == 'reset':
    self.piecetomove = 'none'
    self.destination = 'nowhere'
    self.movementdefined = False
    what_to_say = "Reset confirmed. Say the piece you would like to move, or say a functional operation."
    self.talk.say_something(what_to_say)
    print(what_to_say)
else:
    print("No valid command")
    return

if self.piecetomove == 'none' and piece != 'none':
    self.piecetomove = piece
what_to_say = self.piecetomove + " has been chosen as the piece to move. Give the location to which you would like to move it."
self.talk.say_something(what_to_say)
print(what_to_say)
if self.destination == 'nowhere' and index != 'nowhere' and self.piecetomove != 'none':
    self.destination = index
self.movementdefined = True
what_to_say = self.destination + " has been chosen as the destination."
self.talk.say_something(what_to_say)
print(what_to_say)

# read the setup parameters from setup.dat
#This is the first function to look at. It is entirely
#optional. The limb and distance can be "hard coded" or
#you can even get user input if desired.
def get_setup():
    global image_directory
    file_name = image_directory + "setup.dat"
    try:
        f = open(file_name, "r")
    except ValueError:
        sys.exit("ERROR: setup must be run before this")
    # find limb
    s = string.split(f.readline())
    if len(s) >= 3:
        if s[2] == "left" or s[2] == "right":
            limb = s[2]
        else:
            sys.exit("ERROR: invalid limb in %s" % file_name)
    else:
        sys.exit("ERROR: missing limb in %s" % file_name)
    # find distance to table
    s = string.split(f.readline())
    if len(s) >= 3:
        try:
            distance = float(s[2])
        except ValueError:
            sys.exit("ERROR: invalid distance in %s" % file_name)
        else:
            sys.exit("ERROR: missing distance in %s" % file_name)
    return limb, distance

if __name__=="__main__":
    try:
        rospy.init_node('voicecommands', anonymous = True)
        # get setup parameters—go to function with #2 by it
        limb, distance = get_setup()
        print "limb = ", limb
        print "distance = ", distance
        # create an instance of the class Locate.
        locator = Locate(limb, distance)
        rospy.on_shutdown(locator.clean_shutdown)
        voice = Voice()
        what_to_say = "Press Enter to start initialization: 
voice.talk.say_something(what_to_say)
raw_input("Press Enter to start initialization: ")

    locator.gripper.open()

    # move the arm whose camera you are using close to the board
    # you may wish to change this starting location.
    locator.pose = [locator.cBoard_tray_x,
                    locator.cBoard_tray_y,
locator.cBoard_tray_z,
locator.roll, locator.pitch, locator.yaw]
locator.baxter_ik_move(locator.limb, locator.pose)

# find the chess board
locator.find_cBoard_tray()

# create a list of poses in Baxter's coordinates for each chess board square
board_spot = list()
what_to_say = "Set up board pieces. Then press Enter to begin voice command operation: "]
voice.talk.say_something(what_to_say)
raw_input("Set up board pieces. Then press Enter to begin voice command operation: "]
for i in range (66):
  if i >= 64:
    locator.pose = [copy.copy(locator.cBoard_tray_place[i][0]),
    -0.015
    copy.copy(locator.cBoard_tray_place[i][1]),
    -0.045
    locator.piece_z - 15,
    locator.roll,
    locator.pitch,
    locator.yaw]
  else:
    locator.pose = [copy.copy(locator.cBoard_tray_place[i][0]),
    -0.015
    copy.copy(locator.cBoard_tray_place[i][1]),
    -0.045
    locator.piece_z - 32,
    locator.roll,
    locator.pitch,
    locator.yaw]
  board_spot.append(locator.pose)
  #locator.baxter_ik_move(locator.limb, locator.pose)
  #unpause to enable voice command operation
  voice.paused = False
  what_to_say = "Say the piece you would like to move, or say a functional operation."
  voice.talk.say_something(what_to_say)
  print(what_to_say)
  while not rospy.is_shutdown():
    if the user defined a possible move attempt to perform it once
      if voice.movementdefined and not voice.checkedmove and not voice.waitingforcheck:
        #print the desired move to the terminal for reference
        print("Attempting to move " + voice.piecetomove + " to position " + voice.destination)
        #get the coordinates of the starting and ending positions for the desired move
        loc = game.label_to_loc(voice.destination)
        validmove, piecekilled = game.check_move(voice.piecetomove,loc,voice.whiteturn)
        #request baxter to perform the physical movement
        if validmove:
          #get index of the piece the player wants to move
          if(voice.whiteturn):
            pieceindex = game.white_piece_dict[voice.piecetomove]
          else:
            pieceindex = game.black_piece_dict[voice.piecetomove]
          #get the coordinates of the starting and ending positions for the desired move
          pos1 = 8*(7-pieceindex[1]) + pieceindex[0]
          pos2 = 8*(7-loc[1]) + loc[0]
          voice.paused = True
          if piecekilled == True:
            print("unKilling")
          locator.pick(board_spot[pos2])
          locator.middle(board_spot[65])
          locator.place(board_spot[64])
          locator.middle(board_spot[65])
          print("unPicking...")
locator.pick(board_spot[pos1])
locator.middle(board_spot[65])
print("Placing...")
updatedpose = copy.copy(board_spot[pos2])
updatedpose[2] = board_spot[pos2][2] + .01
locator.place(updatedpose)
locator.middle(board_spot[65])
voice.waitingforcheck = True
what_to_say = "Did Baxter successfully make the move requested? Reply 'Success' or 'Failure'."
voice.talk.say_something(what_to_say)
print(what_to_say)
voice.paused = False
else:
    what_to_say = "Requested move was invalid. Say the piece you would like to move, or say a functional operation."
    voice.talk.say_something(what_to_say)
    print(what_to_say)
    voice.movementdefined = False
    voice.piecetomove = 'none'
    voice.destination = 'nowhere'

winner = False
# if baxter successfully executed the move
# update the virtual board state,
# change turns,
# and reset variables to be ready for next verbal command
if voice.movementdefined and voice.checkedmove:
    if voice.movessuccess:
        validmove = game.move_piece(voice.piecetomove,voice.destination,voice.whiteturn) # update virtual board state
        if not game.check_king_state(voice.whiteturn):
            if voice.whiteturn:
                what_to_say = "Red player wins."
                voice.talk.say_something(what_to_say)
                print(what_to_say)
                rospy.signal_shutdown('Quit')
                break
            else:
                what_to_say = "Black player wins."
                voice.talk.say_something(what_to_say)
                print(what_to_say)
        voice.whiteturn = not voice.whiteturn # change turn between white and black
        game.print_board()
        voice.piecetomove = 'none'
        voice.destination = 'nowhere'
        voice.movementdefined = False
        voice.waitingforcheck = False
        voice.checkedmove = False
        what_to_say = "Say the piece you would like to move, or say a functional operation."
        voice.talk.say_something(what_to_say)
        print(what_to_say)

voice.r.sleep() 
except rospy.ROSInterruptException:
    rospy.loginfo("Voice command script terminated.")
    reset = Reset()
    reset.set_neutral()
    reset.reset_facescreen()
    reset.grippers.reset()
    reset.disable_motors()
    print("Baxter's arms now in neutral position, led display back to rethink log and motors have been disabled.")


speech_commands.launch

<launch>

  <node name="recognizer" pkg="pocketsphinx" type="recognizer.py" output="screen"/>
  <param name="lm" value="$(find baby_steps)/config/speech_commands.lm"/>
  <param name="dict" value="$(find baby_steps)/config/speech_commands.dic"/>
</node>
speech_commands.txt -
one
two
three
four
five
six
seven
eight
alpha
bravo
charlie
delta
echo
foxtrot
golf
hotel
pawn
rook
knight
king
queen
bishop
pause
continue
shutdown
reset
success
failure

speech_commands.dic -
ALPHA   AE L F AH
BISHOP   B IH SH AH P
BRAVO    B R AA V OW
CHARLIE  CH AA R L I Y
CONTINUE  K AH N T IH N Y UW
DELTA    D EH L T AH
ECHO     EH K OW
EIGHT    EY T
FAILURE  F EY L Y ER
FIVE     F AY V
FOUR     F AO R
FOXTROT  F AA K S T R AA T
GOLF     G AA L F
GOLF(2)  G AO L F
HOTEL    HH OW T EH L
KING     K IH NG
KNIGHT   N AH T
ONE      W AH N
ONE(2)   HH W AH N
PAUSE    P AO Z
PAWN     P AO N
QUEEN    K W IY N
RESET    R IY S EH T
ROOK     R UH K
SEVEN    S EH V AH N
SHUTDOWN  SH AH T D AW N
SIX      S IH K S
SUCCESS  S AH K S EH S
THREE    TH R IY
TWO      T UW

speech_commands.lm -
Language model created by QuickLM on Thu Apr 19 17:51:57 EDT 2018
Copyright (c) 1996-2010 Carnegie Mellon University and Alexander I. Rudnicky
The model is in standard ARPA format, designed by Doug Paul while he was at MITRE.

The code that was used to produce this language model is available in Open Source. Please visit http://www.speech.cs.cmu.edu/tools/ for more information.

The (fixed) discount mass is 0.5. The backoffs are computed using the ratio method. This model based on a corpus of 28 sentences and 30 words.

\data
\ngram 1=30
\ngram 2=56
\ngram 3=28
\n
\1-grams:
-0.7782 </s> -0.3010
-0.7782 </s> -0.2218
-2.2253 ALPHA -0.2218
-2.2253 BISHOP -0.2218
-2.2253 BRAVO -0.2218
-2.2253 CHARLIE -0.2218
-2.2253 CONTINUE -0.2218
-2.2253 DELTA -0.2218
-2.2253 ECHO -0.2218
-2.2253 EIGHT -0.2218
-2.2253 FAILURE -0.2218
-2.2253 FIVE -0.2218
-2.2253 FOUR -0.2218
-2.2253 FOXTROT -0.2218
-2.2253 GOLF -0.2218
-2.2253 HOTEL -0.2218
-2.2253 KING -0.2218
-2.2253 KNIGHT -0.2218
-2.2253 ONE -0.2218
-2.2253 PAUSE -0.2218
-2.2253 PAWN -0.2218
-2.2253 QUEEN -0.2218
-2.2253 RESET -0.2218
-2.2253 ROOK -0.2218
-2.2253 SEVEN -0.2218
-2.2253 SHUTDOWN -0.2218
-2.2253 SIX -0.2218
-2.2253 SUCCESS -0.2218
-2.2253 THREE -0.2218
-2.2253 TWO -0.2218

\2-grams:
-1.7482 </s> ALPHA 0.0000
-1.7482 </s> BISHOP 0.0000
-1.7482 </s> BRAVO 0.0000
-1.7482 </s> CHARLIE 0.0000
-1.7482 </s> CONTINUE 0.0000
-1.7482 </s> DELTA 0.0000
-1.7482 </s> EIGHT 0.0000
-1.7482 </s> FAILURE 0.0000
-1.7482 </s> FIVE 0.0000
-1.7482 </s> FOUR 0.0000
-1.7482 </s> FOXTROT 0.0000
-1.7482 </s> GOLF 0.0000
-1.7482 </s> HOTEL 0.0000
-1.7482 </s> KING 0.0000
-1.7482 </s> KNIGHT 0.0000
-1.7482 </s> ONE 0.0000
-1.7482 </s> PAUSE 0.0000
-1.7482 </s> PAWN 0.0000
-1.7482 </s> QUEEN 0.0000
-1.7482 </s> RESET 0.0000
-1.7482 </s> ROOK 0.0000
-1.7482 </s> SEVEN 0.0000
-1.7482 </s> SHUTDOWN 0.0000
speech_commands.log_pronounce -

ALPHA - Main
BISHOP - Main
BRAVO - Main
CHARLIE - Main
speech_commands.sent -
<s> ONE </s>
<s> TWO </s>
<s> THREE </s>
<s> FOUR </s>
<s> FIVE </s>
<s> SIX </s>
<s> SEVEN </s>
<s> EIGHT </s>
<s> ALPHA </s>
<s> BRAVO </s>
<s> CHARLIE </s>
<s> DELTA </s>
<s> ECHO </s>
<s> FOXTROT </s>
<s> GOLF </s>
<s> HOTEL </s>
<s> PAWN </s>
<s> ROOK </s>
<s> KNIGHT </s>
<s> KING </s>
<s> QUEEN </s>
<s> BISHOP </s>
<s> PAUSE </s>
<s> CONTINUE </s>
<s> SHUTDOWN </s>
<s> RESET </s>
<s> SUCCESS </s>
<s> FAILURE </s>

speech_commands.vocab -
ALPHA
BISHOP
BRAVO
CHARLIE
CONTINUE
DELTA
ECHO
EIGHT
FAILURE
FIVE
FOUR
FOXTROT
GOLF
from __future__ import print_function
from Board import Board
from Null import Null

class Game():
    def __init__(self):
        self.initial_board = Board()
        self.piece_dict = {}
        self.white_piece_dict = {}
        self.black_piece_dict = {}
        self.killed_piece = False

def label_to_loc(self, label):
    loc = []
    letters = ['a', 'b', 'c', 'd', 'e', 'f', 'g', 'h']
    numbers = ['1', '2', '3', '4', '5', '6', '7', '8']

    for i in range(8):
        if letters[i] == label[0]:
            loc.append(i)
    for j in range(8):
        if numbers[j] == label[1]:
            loc.append(j)
    return loc

def print_board(self):
    for i in range(8):
        for j in range(8):
            print(self.initial_board.board[i][j].return_piece().identity(), end = " ")
            print("a")
    for i in range(8):
        for j in range(8):
            print(self.initial_board.board[i][j].return_piece().return_color_string(), end = " ")
            print("a")
    for i in range(8):
        for j in range(8):
            print(self.initial_board.board[i][j].return_piece().return_labelp(), end = " ")
            print("a")
    for i in range(8):
        for j in range(8):
            print(self.initial_board.board[i][j].return_loc(), end = " ")
            print("a")
    for i in range(8):
        for j in range(8):
            print(self.initial_board.board[i][j].return_color(), end = " ")
            print("a")
print("us")

def create_piece_dict(self):
    self.create_white_piece_dict()
    self.create_black_piece_dict()

def create_white_piece_dict(self):
    i = 0
    j = 0
    # Pawns
    for n in range(8):
        i, j = self.initial_board.xy_to_ij(n, 1)
        key = self.initial_board.board[i][j].return_piece().return_label
        value = self.initial_board.board[i][j].return_piece().return_loc
        self.white_piece_dict[key] = value
    # Queen
    i, j = self.initial_board.xy_to_ij(3, 0)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.white_piece_dict[key] = value
    # Rooks
    i, j = self.initial_board.xy_to_ij(0, 0)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.white_piece_dict[key] = value
    i, j = self.initial_board.xy_to_ij(7, 0)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.white_piece_dict[key] = value
    # Bishops
    i, j = self.initial_board.xy_to_ij(2, 0)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.white_piece_dict[key] = value
    i, j = self.initial_board.xy_to_ij(5, 0)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.white_piece_dict[key] = value
    # King
    i, j = self.initial_board.xy_to_ij(4, 0)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.white_piece_dict[key] = value
    # Knights
    i, j = self.initial_board.xy_to_ij(1, 0)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.white_piece_dict[key] = value
    i, j = self.initial_board.xy_to_ij(6, 0)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.white_piece_dict[key] = value

def create_black_piece_dict(self):
    i = 0
    j = 0
    # Pawns
    for n in range(8):
        i, j = self.initial_board.xy_to_ij(n, 6)
        key = self.initial_board.board[i][j].return_piece().return_label
        value = self.initial_board.board[i][j].return_piece().return_loc
        self.black_piece_dict[key] = value
    # Queen
    i, j = self.initial_board.xy_to_ij(3, 7)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.black_piece_dict[key] = value
    # Rooks
    i, j = self.initial_board.xy_to_ij(0, 7)
    key = self.initial_board.board[i][j].return_piece().return_label
    value = self.initial_board.board[i][j].return_piece().return_loc
    self.black_piece_dict[key] = value
i, j = self.initial_board.xy_to_ij(7, 7)
key = self.initial_board.board[i][j].return_labelp()
value = self.initial_board.board[i][j].return_locp()
self.black_piece_dict[key] = value

# Bishops
i, j = self.initial_board.xy_to_ij(2, 7)
key = self.initial_board.board[i][j].return_labelp()
value = self.initial_board.board[i][j].return_locp()
self.black_piece_dict[key] = value

i, j = self.initial_board.xy_to_ij(5, 7)
key = self.initial_board.board[i][j].return_labelp()
value = self.initial_board.board[i][j].return_locp()
self.black_piece_dict[key] = value

# King
i, j = self.initial_board.xy_to_ij(4, 7)
key = self.initial_board.board[i][j].return_labelp()
value = self.initial_board.board[i][j].return_locp()
self.black_piece_dict[key] = value

# Knights
i, j = self.initial_board.xy_to_ij(1, 7)
key = self.initial_board.board[i][j].return_labelp()
value = self.initial_board.board[i][j].return_locp()
self.black_piece_dict[key] = value

i, j = self.initial_board.xy_to_ij(6, 7)
key = self.initial_board.board[i][j].return_labelp()
value = self.initial_board.board[i][j].return_locp()
self.black_piece_dict[key] = value

# function which prints the contents of white and black dictionaries
def print_piece_dict(self):
    for key, value in self.white_piece_dict.items():
        print(key, ':', value)
    print('
')
    for key, value in self.black_piece_dict.items():
        print(key, ':', value)

# function which iterates through the dictionary keys and returns if there is a match to label
def check_piece_dict(self, label, white_turn):
    if white_turn:
        for key in self.white_piece_dict.keys():
            if label == key:
                return True
    else:
        for key in self.black_piece_dict.keys():
            if label == key:
                return True
    return False

# function which generates a list of valid moves for a piece which wants to move
def generate_moves(self, locp, white_turn):
    i = 0
    j = 0
    move_list = []
    piece_type = ""
    i, j = self.initial_board.xy_to_ij(locp[0], locp[1])
    piece = self.initial_board.board[i][j].return_piece()
    piece_type = piece.identity()
    currentX = piece.return_locp()[0]
    currentY = piece.return_locp()[1]

    if piece_type == "Pawn":
        if white_turn:
            d1 = self.pawn_d1(currentX, currentY)
            u = self.pawn_u(currentX, currentY)
            u2 = self.pawn_u2(currentX, currentY)
            d2 = self.pawn_d2(currentX, currentY)

            if d1:
                move_list.append([currentX-1, currentY+1])
if(u):
    move_list.append([currentX, currentY+1])
elif(u2):
    move_list.append([currentX, currentY+2])
if(d2):
    move_list.append([currentX+1, currentY+1])
else:
    d4 = self.pawn_d4(currentX, currentY)
    l  = self.pawn_l(currentX, currentY)
    l2 = self.pawn_l2(currentX, currentY)
    d3 = self.pawn_d3(currentX, currentY)
    if(d4):
        move_list.append([currentX-1, currentY-1])
    if(l):
        move_list.append([currentX, currentY-1])
    if(l2):
        move_list.append([currentX, currentY-2])
    if(d3):
        move_list.append([currentX+1, currentY-1])
elif(piece_type == "Queen"):
    move_list = self.f_moves(currentX, currentY, move_list)
    move_list = self.d1_moves(currentX, currentY, move_list)
    move_list = self.u_moves(currentX, currentY, move_list)
    move_list = self.d2_moves(currentX, currentY, move_list)
    move_list = self.r_moves(currentX, currentY, move_list)
    move_list = self.d3_moves(currentX, currentY, move_list)
    move_list = self.l_moves(currentX, currentY, move_list)
    move_list = self.d4_moves(currentX, currentY, move_list)
elif(piece_type == "Rook"):
    move_list = self.f_moves(currentX, currentY, move_list)
    move_list = self.u_moves(currentX, currentY, move_list)
    move_list = self.r_moves(currentX, currentY, move_list)
    move_list = self.l_moves(currentX, currentY, move_list)
elif(piece_type == "Bishop"):
    move_list = self.d1_moves(currentX, currentY, move_list)
    move_list = self.d2_moves(currentX, currentY, move_list)
    move_list = self.d3_moves(currentX, currentY, move_list)
    move_list = self.d4_moves(currentX, currentY, move_list)
elif(piece_type == "King"):
    move_list = self.f_move(currentX, currentY, move_list)
    move_list = self.d1_move(currentX, currentY, move_list)
    move_list = self.u_move(currentX, currentY, move_list)
    move_list = self.d2_move(currentX, currentY, move_list)
    move_list = self.r_move(currentX, currentY, move_list)
    move_list = self.d3_move(currentX, currentY, move_list)
    move_list = self.l_move(currentX, currentY, move_list)
    move_list = self.d4_move(currentX, currentY, move_list)
elif(piece_type == "Knight"):
    move_list = self.n1_move(currentX, currentY, move_list)
    move_list = self.n2_move(currentX, currentY, move_list)
    move_list = self.n3_move(currentX, currentY, move_list)
    move_list = self.n4_move(currentX, currentY, move_list)
    move_list = self.n5_move(currentX, currentY, move_list)
    move_list = self.n6_move(currentX, currentY, move_list)
    move_list = self.n7_move(currentX, currentY, move_list)
    move_list = self.n8_move(currentX, currentY, move_list)
return move_list

"" PAWN CARDINAL DIRECTION BOOLEAN FUNCTIONS ""

def pawn_u(self, currentX, currentY):
    i = 0
    new_i = 0
    j = 0
    new_j = 0
    i,j = self.initial_board.xy_to_ij(currentX, currentY)
    if(currentY+1 > 7):
        return False
else:
    newi,newj = self.initial_board.xy_to_ij(currentX,currentY+1)

enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()

if(enemy_color == "None"):
    return True
else:
    return False

def pawn_l(self,currentX,currentY):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentY-1 < 0):
        return False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX,currentY-1)

enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()

if(enemy_color == "None"):
    return True
else:
    return False

def pawn_u2(self,currentX,currentY):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentY+2 > 7):
        return False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX,currentY+2)

enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()

if(self.initial_board.board[i][j].return_piece().init_loc == False):
    return False
if(enemy_color == "None"):
    return True
else:
    return False

def pawn_l2(self,currentX,currentY):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentY-2 < 0):
        return False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX,currentY-2)

enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()

if(self.initial_board.board[i][j].return_piece().init_loc == False):
    return False
if(enemy_color == "None"):
    return True
else:
    return False

def pawn_d1(self,currentX,currentY):
    j = 0
    newi = 0
    j = 0

newj = 0
i,j = self.initial_board.xy_to_ij(currentX,currentY)
if(currentX-1 < 0 or currentY+1 > 7):
    return False
else:
    newi,newj = self.initial_board.xy_to_ij(currentX-1,currentY+1)

piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()

if(enemy_color == "None"):
    return False
else:
    if(enemy_color == piece_color):
        return False
    else:
        return True

def pawn_d2(self,currentX,currentY):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentX+1 > 7 or currentY+1 > 7):
        return False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX+1,currentY+1)

        piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()

        if(enemy_color == "None"):
            return False
        else:
            if(enemy_color == piece_color):
                return False
            else:
                return True

def pawn_d3(self,currentX,currentY):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentX+1 > 7 or currentY-1 < 0):
        return False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX+1,currentY-1)

        piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()

        if(enemy_color == "None"):
            return False
        else:
            if(enemy_color == piece_color):
                return False
            else:
                return True

def pawn_d4(self,currentX,currentY):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentX-1 < 0 or currentY-1 < 0):
        return False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX-1,currentY-1)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()

if(enemy_color == "None"):
    return False
else:
    if(enemy_color == piece_color):
        return False
    else:
        return True

"END OF PAWN CARDINAL DIRECTION BOOLEAN FUNCTIONS"
"START OF KNIGHT SPECIFIC MOVEMENT CHECKS"

def n1_move(self, currentX, currentY, move_list):
    X = currentX - 1
    Y = currentY + 2
    i = 0
    j = 0
    i, j = self.initial_board.xy_to_ij(currentX, currentY)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check = self.n_check(X, Y, piece_color)
    if(check):
        move_list.append([X, Y])
        return move_list
    else:
        return move_list

def n2_move(self, currentX, currentY, move_list):
    X = currentX + 1
    Y = currentY + 2
    i = 0
    j = 0
    i, j = self.initial_board.xy_to_ij(currentX, currentY)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check = self.n_check(X, Y, piece_color)
    if(check):
        move_list.append([X, Y])
        return move_list
    else:
        return move_list

def n3_move(self, currentX, currentY, move_list):
    X = currentX + 2
    Y = currentY + 1
    i = 0
    j = 0
    i, j = self.initial_board.xy_to_ij(currentX, currentY)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check = self.n_check(X, Y, piece_color)
    if(check):
        move_list.append([X, Y])
        return move_list
    else:
        return move_list

def n4_move(self, currentX, currentY, move_list):
    X = currentX + 2
    Y = currentY - 1
    i = 0
    j = 0
    i, j = self.initial_board.xy_to_ij(currentX, currentY)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check = self.n_check(X, Y, piece_color)
    if(check):
        move_list.append([X, Y])
        return move_list
    else:
        return move_list

def n5_move(self, currentX, currentY, move_list):
    X = currentX + 1
    Y = currentY - 2
    i = 0
    j = 0
    i, j = self.initial_board.xy_to_ij(currentX, currentY)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
color = self.n_check(X,Y,piece_color)
if(color):
    move_list.append([X,Y])
    return move_list
else:
    return move_list

def n6_move(self, currentX, currentY, move_list):
    X = currentX - 1
    Y = currentY - 2
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(currentX, currentY)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
color = self.n_check(X,Y,piece_color)
if(color):
    move_list.append([X,Y])
    return move_list
else:
    return move_list

def n7_move(self, currentX, currentY, move_list):
    X = currentX - 2
    Y = currentY - 1
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(currentX, currentY)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
color = self.n_check(X,Y,piece_color)
if(color):
    move_list.append([X,Y])
    return move_list
else:
    return move_list

def n8_move(self, currentX, currentY, move_list):
    X = currentX - 2
    Y = currentY + 1
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(currentX, currentY)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
color = self.n_check(X,Y,piece_color)
if(color):
    move_list.append([X,Y])
    return move_list
else:
    return move_list

''END OF KNIGHT SPECIFIC MOVEMENT CHECKS''

''START OF KING SPECIFIC MOVEMENT CHECKS''

def f_move(self, currentX, currentY, move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
color,enemy_piece = self.f_check(X,Y,piece_color)
if(color):
    move_list.append([X-1,Y])
    return move_list
else:
    return move_list

def d1_move(self, currentX, currentY, move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
color,enemy_piece = self.d1_check(X,Y,piece_color)
if(color):
    move_list.append([X-1,Y])
    return move_list
else:
    return move_list

''END OF KING SPECIFIC MOVEMENT CHECKS''
move_list.append([X-1,Y+1])
return move_list
else:
    return move_list
def u_move(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check,enemy_piece = self.u_check(X,Y,piece_color)
    if(check):
        move_list.append([X,Y+1])
        return move_list
    else:
        return move_list
def d2_move(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check,enemy_piece = self.d2_check(X,Y,piece_color)
    if(check):
        move_list.append([X+1,Y+1])
        return move_list
    else:
        return move_list
def r_move(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
    piece_color = self.initial_board.board[i][j].return_color_string()
    check,enemy_piece = self.r_check(X,Y,piece_color)
    if(check):
        move_list.append([X+1,Y])
        return move_list
    else:
        return move_list
def d3_move(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check,enemy_piece = self.d3_check(X,Y,piece_color)
    if(check):
        move_list.append([X+1,Y-1])
        return move_list
    else:
        return move_list
def l_move(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check,enemy_piece = self.l_check(X,Y,piece_color)
    if(check):
        move_list.append([X,Y-1])
        return move_list
    else:
        return move_list
def d4_move(self,currentX, currentY, move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i, j = self.initial_board.xy_to_ij(X, Y)
    piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
    check, enemy_piece = self.d4_check(X, Y, piece_color)
    if(check):
        move_list.append([X - 1, Y - 1])
        return move_list
    else:
        return move_list

"""END OF KING SPECIFIC MOVEMENT CHECKS"
"""START OF CARDINAL DIRECTION CHECKS"
def d4_check(self, currentX, currentY, piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i, j = self.initial_board.xy_to_ij(currentX, currentY)
    if(currentX - 1 < 0 or currentY - 1 < 0):
        return False, False
    else:
        newi, newj = self.initial_board.xy_to_ij(currentX - 1, currentY - 1)
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
        if(enemy_color == "None"):
            return True, False
        else:
            if(enemy_color == piece_color):
                return False, False
            else:
                return True, True
def d3_check(self, currentX, currentY, piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i, j = self.initial_board.xy_to_ij(currentX, currentY)
    if(currentX + 1 > 7 or currentY - 1 < 0):
        return False, False
    else:
        newi, newj = self.initial_board.xy_to_ij(currentX + 1, currentY - 1)
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
        if(enemy_color == "None"):
            return True, False
        else:
            if(enemy_color == piece_color):
                return False, False
            else:
                return True, True
def d2_check(self, currentX, currentY, piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i, j = self.initial_board.xy_to_ij(currentX, currentY)
    if(currentX + 1 > 7 or currentY + 1 > 7):
        return False, False
    else:
        newi, newj = self.initial_board.xy_to_ij(currentX + 1, currentY + 1)
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
if(enemy_color == "None"):
    return True,False
else:
    if(enemy_color == piece_color):
        return False,False
    else:
        return True,True
def d1_check(self,currentX,currentY,piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentX-1 < 0 or currentY+1 > 7):
        return False,False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX-1,currentY+1)
    enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
    if(enemy_color == "None"):
        return True,False
    else:
        if(enemy_color == piece_color):
            return False,False
        else:
            return True,True
def l_check(self,currentX,currentY,piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentY-1 < 0):
        return False,False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX,currentY-1)
    enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
    if(enemy_color == "None"):
        return True,False
    else:
        if(enemy_color == piece_color):
            return False,False
        else:
            return True,True
def u_check(self,currentX,currentY,piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX,currentY)
    if(currentY+1 > 7):
        return False,False
    else:
        newi,newj = self.initial_board.xy_to_ij(currentX,currentY+1)
    enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
    if(enemy_color == "None"):
        return True,False
    else:
        if(enemy_color == piece_color):
            return False,False
        else:
```python
def r_check(self, currentX, currentY, piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX, currentY)
    if(currentX + 1 > 7):
        return False, False
    else:
        newi, newj = self.initial_board.xy_to_ij(currentX + 1, currentY)
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
        if(enemy_color == "None"):
            return True, False
        else:
            if(enemy_color == piece_color):
                return False, False
            else:
                return True, True

def f_check(self, currentX, currentY, piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(currentX, currentY)
    if(currentX - 1 < 0):
        return False, False
    else:
        newi, newj = self.initial_board.xy_to_ij(currentX - 1, currentY)
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
        if(enemy_color == "None"):
            return True, False
        else:
            if(enemy_color == piece_color):
                return False, False
            else:
                return True, True

# END of CARDINAL DIRECTION CHECKS
#function which does a check for all knight movements
def n_check(self, X, Y, piece_color):
    i = 0
    newi = 0
    j = 0
    newj = 0
    i,j = self.initial_board.xy_to_ij(X, Y)
    if(X < 0 or X > 7 or Y < 0 or Y > 7):
        return False
    else:
        newi, newj = self.initial_board.xy_to_ij(X, Y)
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
        if(enemy_color == "None"):
            return True
        else:
            if(enemy_color == piece_color):
                return False
            else:
                return True

#START OF QUEEN/BISHOP/ROOK MOVEMENT CHECKS
def d4_moves(self, currentX, currentY, move_list):
    X = currentX
    Y = currentY
```

i = 0
j = 0
i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
check,enemy_piece = self.d4_check(X,Y,piece_color)
while(check):
    move_list.append([X-1,Y-1])
    Y = Y - 1
    X = X - 1
    if(enemy_piece):
        break
    check,enemy_piece = self.d4_check(X,Y,piece_color)
return move_list

def d3_moves(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
check,enemy_piece = self.d3_check(X,Y,piece_color)
while(check):
    move_list.append([X+1,Y-1])
    Y = Y - 1
    X = X + 1
    if(enemy_piece):
        break
    check,enemy_piece = self.d3_check(X,Y,piece_color)
return move_list

def d2_moves(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
check,enemy_piece = self.d2_check(X,Y,piece_color)
while(check):
    move_list.append([X+1,Y+1])
    Y = Y + 1
    X = X + 1
    if(enemy_piece):
        break
    check,enemy_piece = self.d2_check(X,Y,piece_color)
return move_list

def d1_moves(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
check,enemy_piece = self.d1_check(X,Y,piece_color)
while(check):
    move_list.append([X-1,Y+1])
    Y = Y + 1
    X = X - 1
    if(enemy_piece):
        break
    check,enemy_piece = self.d1_check(X,Y,piece_color)
return move_list

def l_moves(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
```python
j = 0
i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
check,enemy_piece = self.l_check(X,Y,piece_color)
while(check):
    move_list.append([X,Y-1])
    Y = Y - 1
    if(enemy_piece):
        break
    check,enemy_piece = self.l_check(X,Y,piece_color)
return move_list

def u_moves(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
check,enemy_piece = self.u_check(X,Y,piece_color)
while(check):
    move_list.append([X,Y+1])
    Y = Y + 1
    if(enemy_piece):
        break
    check,enemy_piece = self.u_check(X,Y,piece_color)
return move_list

def f_moves(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
check,enemy_piece = self.f_check(X,Y,piece_color)
while(check):
    move_list.append([X-1,Y])
    X = X - 1
    if(enemy_piece):
        break
    check,enemy_piece = self.f_check(X,Y,piece_color)
return move_list

def r_moves(self,currentX,currentY,move_list):
    X = currentX
    Y = currentY
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(X,Y)
piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
check,enemy_piece = self.r_check(X,Y,piece_color)
while(check):
    move_list.append([X+1,Y])
    X = X + 1
    if(enemy_piece):
        break
    check,enemy_piece = self.r_check(X,Y,piece_color)
return move_list

"END OF KING/BISHOP/ROOK MOVEMENT CHECKS"

#function that was used for testing purposes
def place_piece(self,piece,loc,colorp):
    i = 0
    j = 0
    i,j = self.initial_board.xy_to_ij(loc[0],loc[1])
    self.initial_board.board[i][j].change_square_state()
    self.initial_board.board[i][j].set_piece(piece)
    self.initial_board.board[i][j].return_piece().set_locp(loc[0],loc[1])
    self.initial_board.board[i][j].return_piece().set_color_string(colorp)
    self.initial_board.board[i][j].return_piece().set_labelp("PT")

#function which is used to remove a key value pair from a either the white or black dictionary.
def remove_from_dict(self,label,white_turn):
```
if(white_turn):
    del self.black_piece_dict[label]
else:
    del self.white_piece_dict[label]
#function which determines if the king piece has been killed or not
def check_king_state(self,white_turn):
    if(white_turn):
        for key in self.black_piece_dict.keys():
            if('K' == key):
                return True
    else:
        for key in self.white_piece_dict.keys():
            if('K' == key):
                return True
    return False
#function which returns true if a move is valid false otherwise
def check_move(self,label,loc,white_turn):
    self.killed_piece = False
    if(self.check_piece_dict(label,white_turn)):
        if(white_turn):
            current_loc = self.white_piece_dict[label]
        else:
            current_loc = self.black_piece_dict[label]
        i,j,newi,newj = 0,0,0,0
        i,j = self.initial_board.xy_to_ij(current_loc[0],current_loc[1])
        newi,newj = self.initial_board.xy_to_ij(loc[0],loc[1])
        piece_color = self.initial_board.board[i][j].return_piece().return_color_string()
        enemy_color = self.initial_board.board[newi][newj].return_piece().return_color_string()
        for move in self.generate_moves(current_loc,white_turn):
            if(move == loc):
                if(enemy_color == "None"):
                    self.killed_piece = False
                else:
                    if(piece_color == enemy_color):
                        self.killed_piece = False
                    else:
                        self.killed_piece = True
                    return True,self.killed_piece
    return False,self.killed_piece
#function which takes care of moving a piece and updating the board state
def move_piece(self,label,loc_label,white_turn):
    i=0
    j=0
    newi=0
    newj=0
    current_init_loc = True
    loc = self.label_to_loc(loc_label)
    if(self.check_piece_dict(label,white_turn)):
        if(white_turn):
            current_loc = self.white_piece_dict[label]
        else:
            current_loc = self.black_piece_dict[label]
    else:
        print("Invalid Move")
        return False
    i,j = self.initial_board.xy_to_ij(current_loc[0],current_loc[1])
    newi,newj = self.initial_board.xy_to_ij(loc[0],loc[1])
    piece_type = self.initial_board.board[i][j].return_piece().identity()
    check,isKilled = self.check_move(label,loc,white_turn)
    victim_label = self.initial_board.board[newi][newj].return_piece().return_labelp()
    print(isKilled)
    if isKilled:
        self.remove_from_dict(victim_label,white_turn)
if(check):
    if(piece_type == "Pawn"):
        self.initial_board.board[i][j].return_piece().set_init_loc(False)
        current_init_loc = self.initial_board.board[i][j].return_piece().init_loc
        if(abs(loc[1]-current_loc[1])==2): #just for pawns
            current_piece = self.initial_board.board[i][j].return_piece()
            current_piece_color = self.initial_board.board[i][j].return_piece().return_colorp()
            current_color_string = self.initial_board.board[i][j].return_piece().return_color_string()
            current_label = self.initial_board.board[i][j].return_piece().return_lablep()

            self.initial_board.board[i][j].change_square_state()
            self.initial_board.board[newi][newj].change_square_state()
            self.initial_board.board[i][j].set_piece(Null())
            self.initial_board.board[i][j].return_piece().set_labelp("Null")
            self.initial_board.board[i][j].return_piece().set_locp(current_loc[0],current_loc[1])
            self.initial_board.board[i][j].return_piece().set_color_string("None")

            self.initial_board.board[newi][newj].set_piece(current_piece)
            self.initial_board.board[newi][newj].return_piece().set_colorp(current_piece_color)
            self.initial_board.board[newi][newj].return_piece().set_labelp(current_label)
            self.initial_board.board[newi][newj].return_piece().set_color_string(current_color_string)

            self.initail_board.board[newi][newj].return_piece().set_init_loc(current_init_loc)

    if(white_turn):
        self.white_piece_dict[label] = loc
    else:
        self.black_piece_dict[label] = loc
    return True
else:
    print("Invalid Move")
    return False

Board.py

from Pawn import Pawn
from Square import Square
from Null import Null
from Queen import Queen
from Rook import Rook
from Bishop import Bishop
from King import King
from Knight import Knight

class Board():
    def __init__(self):
        letters = ['a','b','c','d','e','f','g','h']
        numbers = ['1','2','3','4','5','6','7','8']

        self.board = []

        for j in range(8):
            column = []
            for i in range(8):
                column.append(0)
            self.board.append(column)

        x = 0
        y = 0

        for i in range(8):
            for j in range(8):
                self.board[i][j] = Square()
                x,y = self.ij_to_xy(i,j)

                self.board[i][j].set_piece(Null())
if(i%2==0):
    if(j%2==0):
        self.board[i][j].change_color()
    else:
        if(j%2!=0):
            self.board[i][j].change_color()

def initialize_board(self):
    i = 0
    j = 0
    pawn_labels = [“P1”, “P2”, “P3”, “P4”, “P5”, “P6”, “P7”, “P8”]
    queen_label = “Q”
    rook_labels = [“R1”, “R2”]
    bishop_labels = [“B1”, “B2”]
    king_label = “K”
    knight_labels = [“N1”, “N2”]

    #White Pawns
    for n in range(8):
        i,j = self.xy_to_ij(n,1)
        self.board[i][j].change_square_state()
        self.board[i][j].set_piece(Pawn())
        self.board[i][j].return_piece().set_labelp(pawn_labels[n])
        self.board[i][j].return_piece().set_locp(n,1)
        self.board[i][j].return_piece().set_color_string(“White”)

    #White Queen
    i,j = self.xy_to_ij(3,0)
    self.board[i][j].change_square_state()
    self.board[i][j].set_piece(Queen())
    self.board[i][j].return_piece().set_labelp(queen_label)
    self.board[i][j].return_piece().set_locp(3,0)
    self.board[i][j].return_piece().set_color_string(“White”)

    #White Rooks
    i,j = self.xy_to_ij(0,0)
    self.board[i][j].change_square_state()
    self.board[i][j].set_piece(Rook())
    self.board[i][j].return_piece().set_labelp(rook_labels[0])
    self.board[i][j].return_piece().set_locp(0,0)
    self.board[i][j].return_piece().set_color_string(“White”)

    i,j = self.xy_to_ij(7,0)
    self.board[i][j].change_square_state()
    self.board[i][j].set_piece(Rook())
    self.board[i][j].return_piece().set_labelp(rook_labels[1])
    self.board[i][j].return_piece().set_locp(7,0)
    self.board[i][j].return_piece().set_color_string(“White”)

    #White Bishops
    i,j = self.xy_to_ij(2,0)
    self.board[i][j].change_square_state()
    self.board[i][j].set_piece(Bishop())
    self.board[i][j].return_piece().set_labelp(bishop_labels[0])
    self.board[i][j].return_piece().set_locp(2,0)
    self.board[i][j].return_piece().set_color_string(“White”)

    i,j = self.xy_to_ij(5,0)
    self.board[i][j].change_square_state()
    self.board[i][j].set_piece(Bishop())
self.board[i][j].return_piece().set_label(bishop_labels[1])
self.board[i][j].return_piece().set_loc(5,0)
self.board[i][j].return_piece().set_color_string("White")

#White King

i,j = self.xy_to_ij(4,0)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(King())
self.board[i][j].return_piece().set_label(king_label)
self.board[i][j].return_piece().set_loc(4,0)
self.board[i][j].return_piece().set_color_string("White")

#White Knights

i,j = self.xy_to_ij(1,0)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Knight())
self.board[i][j].return_piece().set_label(knight_labels[0])
self.board[i][j].return_piece().set_loc(1,0)
self.board[i][j].return_piece().set_color_string("White")

i,j = self.xy_to_ij(6,0)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Knight())
self.board[i][j].return_piece().set_label(knight_labels[1])
self.board[i][j].return_piece().set_loc(6,0)
self.board[i][j].return_piece().set_color_string("White")

#Black Pawns

for n in range(8):
    i,j = self.xy_to_ij(7-n,6)
    self.board[i][j].change_square_state()
    self.board[i][j].set_piece(Pawn())
    self.board[i][j].return_piece().change_color()
    self.board[i][j].return_piece().set_label(pawn_labels[n])
    self.board[i][j].return_piece().set_loc(7-n,6)
    self.board[i][j].return_piece().set_color_string("Black")

#Black Queen

i,j = self.xy_to_ij(3,7)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Queen())
self.board[i][j].return_piece().set_label(queen_label)
self.board[i][j].return_piece().set_loc(3,7)
self.board[i][j].return_piece().set_color_string("Black")

#Black Rooks

i,j = self.xy_to_ij(0,7)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Rook())
self.board[i][j].return_piece().set_label(rook_labels[1])
self.board[i][j].return_piece().set_loc(0,7)
self.board[i][j].return_piece().set_color_string("Black")

i,j = self.xy_to_ij(7,7)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Rook())
self.board[i][j].return_piece().set_label(rook_labels[0])
self.board[i][j].return_piece().set_loc(7,7)
self.board[i][j].return_piece().set_color_string("Black")

#Black Bishops

i,j = self.xy_to_ij(2,7)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Bishop())
self.board[i][j].return_piece().set_label(bishop_labels[1])
i,j = self.xy_to_ij(5,7)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Bishop())
self.board[i][j].return_piece().set_labelp(bishop_labels[0])
self.board[i][j].return_piece().set_locp(5,7)
self.board[i][j].return_piece().set_color_string("Black")

#White King
i,j = self.xy_to_ij(4,7)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(King())
self.board[i][j].return_piece().set_labelp(king_label)
self.board[i][j].return_piece().set_locp(4,7)
self.board[i][j].return_piece().set_color_string("Black")

#White Knights
i,j = self.xy_to_ij(1,7)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Knight())
self.board[i][j].return_piece().set_labelp(knight_labels[1])
self.board[i][j].return_piece().set_locp(1,7)
self.board[i][j].return_piece().set_color_string("Black")

ij = self.xy_to_ij(6,7)
self.board[i][j].change_square_state()
self.board[i][j].set_piece(Knight())
self.board[i][j].return_piece().set_labelp(knight_labels[0])
self.board[i][j].return_piece().set_locp(6,7)
self.board[i][j].return_piece().set_color_string("Black")

def ij_to_xy(self,i,j):
    x = j
    y = 7 - i
    return x,y
def xy_to_ij(self,x,y):
    j = 7 - y
    i = x
    return i,j

Square.py

def __init__(self):
    self.hasPiece = False
    self.isBlack = True
    self.label = "a1"
    self.piece = Piece()
    self.locX = 0
    self.locY = 0
    self.loc = [self.locX,self.locY]
def change_square_state(self):
    self.hasPiece = not self.hasPiece
def return_loc(self):
    return self.loc
def return_locX(self):
    return self.real_locX
def return_locY(self):
    return self.real_locY
def set_loc(self,X,Y):
self.loc = [X,Y]
self.locX = X
self.locY = Y

def set_locX(self,X):
    self.locX = X
    self.loc = [self.locX,self.locY]

def set_locY(self,Y):
    self.locY = Y
    self.loc = [self.locX,self.locY]

def change_color(self):
    self.isBlack = not self.isBlack

def return_color(self):
    return self.isBlack

def set_label(self,label):
    self.label = label

def return_label(self):
    return self.label

def return_square_state(self):
    return self.hasPiece

def set_piece(self,piece):
    self.piece = piece

def return_piece(self):
    return self.piece

Piece.py

class Piece():
    def __init__(self):
        self.labelp = " "
        self.isWhite = True
        self.color_string = "None"
        self.locXp = 0
        self.locYp = 0
        self.locp = [self.locXp,self.locYp]

    def identity(self):
        return self.__class__.__name__

    def set_labelp(self,label):
        self.labelp = label

    def return_labelp(self):
        return self.labelp

    def return_locp(self):
        return self.locp

    def set_locp(self,Xp,Yp):
        self.locp = [Xp,Yp]

    def return_color_string(self):
        return self.color_string

    def set_color_string(self,color):
        self.color_string = color

    def return_isWhite(self):
        return self.isWhite

    def change_colorp(self):
        self.isWhite = not self.isWhite

    def set_colorp(self,colorp):
        self.isWhite = colorp

    def return_locXp(self):
        return self.locXp

    def return_locYp(self):
        return self.locYp

    def set_locXp(self,Xp):
        self.locXp = Xp
        self.locp = [self.locXp,self.locYp]

    def set_locYp(self,Yp):
        self.locYp = Yp
        self.locp = [self.locXp,self.locYp]
self.locYp = Yp
self.locp = [self.locXp, self.locYp]

**Queen.py**
from Piece import Piece
class Queen(Piece):
    def __init__(self):
        Piece.__init__(self)

**Pawn.py**
from Piece import Piece
class Pawn(Piece):
    def __init__(self):
        Piece.__init__(self)
    self.init_loc = True
    def set_init_loc(self, init_loc):
        self.init_loc = init_loc

**Rook.py**
from Piece import Piece
class Rook(Piece):
    def __init__(self):
        Piece.__init__(self)

**Bishop.py**
from Piece import Piece
class Bishop(Piece):
    def __init__(self):
        Piece.__init__(self)

**Knight.py**
from Piece import Piece
class Knight(Piece):
    def __init__(self):
        Piece.__init__(self)

**King.py**
from Piece import Piece
class King(Piece):
    def __init__(self):
        Piece.__init__(self)

**Null.py**
from Piece import Piece
class Null(Piece):
    def __init__(self):
        Piece.__init__(self)
        #def print_n():
        #print("n")